Transport Canada Transports Canada

TP 3702E

ARCTIC TEMPERATURE AND WIND CONDITIONS RELATED TO SHIP-HULL STEEL

Prepared for

Transportation Development Centre
Policy and Coordination Group
Transport Canada

by

Atmospheric Environment Service
Environment Canada

May 1989

Canada

CA1
DTC 800
89
A67

.CA1
DTC 800
89
A67

TP 3702E

CA1
DTC800-
89
A67

429129

41.D

Arctic Temperature And Wind Conditions Related to Ship-Hull Steel

by

J.B. Maxwell
Superintendent, Arctic Climatology Section
Atmospheric Environment Service
Environment Canada

Library and Information Centre / Centre de Documentation (BSLA)
RECEIVED - REÇU
MAR 14 1990
Transport Canada / Transports Canada

May 1989

429129

DDN 420752

90-05806/

The contents of this report reflect the views of the author and not necessarily the official views or opinions of the Transportation Development Centre, Policy and Coordination Group, Transport Canada.

Un sommaire en français de ce rapport est inclus avant la Table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.	2. Project No.	3. Recipient's Catalogue No.
TP 3702E	4046	

4. Title and Subtitle	5. Publication Date
Arctic Temperature and Wind Conditions Related to Ship-Hull Steel	May 1989
	6. Performing Organization Document No. —
7. Author(s) J.B. Maxwell	8. Transport Canada File No. D 1460-129-5
9. Performing Organization Name and Address Environment Canada Atmospheric Environment Service Canadian Climate Centre 4905 Dufferin Street Downsview, Ontario M3H 5T4	10. DSS File No. —
	11. DSS or Transport Canada Contract No. —
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 200 René Lévesque Blvd. West West Tower, Suite 601 Montreal, Quebec H2Z 1X4	13. Type of Publication and Period Covered Final (1953 – 1976)
	14. Project Officer I.M. Bayly

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

The designer of a ship intended for service in the Canadian Arctic must ensure that materials selected for the above-water hull and superstructure will not be critically affected by atmospheric conditions. The report describes a study which collected available records of atmospheric temperature and wind speed over a period of years and processed this data to identify zones of reasonably consistent conditions and representative values of temperature and wind speed within each zone. A cooling index was also reported which combined the effects of temperature and wind speed. The value of these results to ship designers is limited as the data came mainly from coastal observing stations. Collection of data from marine areas is recommended to confirm or modify the results.

17. Key Words	18. Distribution Statement
Ship Hull Steel, Cold Weather, Climate, Arctic Temperature, Wind.	Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	x, 40 + appendix	Nil

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada	2. N° de l'étude	3. N° de catalogue du destinataire
TP 3702E	4046	

4. Titre et sous-titre	5. Date de la publication
Arctic Temperature and Wind Conditions Related to Ship-Hull Steel	Mai 1989
	6. N° du document de l'organisme exécutant —

7. Auteur(s)	8. N° de dossier — Transports Canada
J.B. Maxwell	D 1460-129-5

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Environnement Canada Service de l'environnement atmosphérique Centre canadien de climatologie 4905, rue Dufferin Downsview (Ontario) M3H 5T4	—
	11. N° de contrat — ASC ou Transports Canada —

12. Nom et adresse de l'organisme parrain	13. Genre de publication et période visée
Centre de développement des transports (CDT) 200 ouest, boul. René-Lévesque Tour ouest, suite 601 Montréal (Québec) H2Z 1X4	Finale (1953 – 1976)
	14. Agent de projet I.M. Bayly

15. Remarques additionnelles (Programmes de financement, titres de publications connexes, etc.)

16. Résumé

Le concepteur de navires destinés à la navigation dans l'Arctique canadien doit, pour la superstructure et la partie non immergée de la coque, choisir des matériaux dont les propriétés ne risquent pas d'être gravement altérées par les conditions atmosphériques régnant dans cette région du globe. Ce rapport présente les relevés atmosphériques de températures et de vitesses du vent effectués sur un certain nombre d'années et traités de façon à en dégager les zones où les conditions sont suffisamment stables, ainsi que les valeurs représentatives des paramètres considérés pour chaque zone. Les chercheurs ont également défini un indice de refroidissement prenant en compte l'effet combiné du froid et du vent. Les résultats de cette recherche sont cependant d'utilité restreinte pour les concepteurs de navires car les données utilisées proviennent principalement des stations météo côtières. Il conviendrait donc de procéder à la collecte de nouvelles données, en mer cette fois, dans le but de confirmer ou d'infirmer les résultats obtenus jusqu'ici.

17. Mots clés	18. Diffusion
Coque, superstructure, Arctique, navigation aux basses températures, vitesse du vent, température.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	x, 40 + annexe	Nil

SUMMARY

Ships intended for service in the Canadian Arctic must not be critically affected by atmospheric conditions. Many of the steels used in ship construction exhibit unacceptably brittle behaviour at temperatures below critical thresholds. It is important to know the temperatures and heat transfer rates to which a ship's structure may be exposed when operating in arctic waters before selecting the steel for that ship.

This report describes a study with a twofold purpose:

- to prepare design temperature and cooling rate information that would be pertinent for selecting ship-hull steel criteria to be applied to vessels entering Canadian Arctic waters and thereby subject to the Arctic Shipping Pollution Prevention Regulations (ASPPR), and
- to provide a data base of weather information for possible future studies on this subject.

The reported study covered the area of the existing shipping control zones prescribed under ASPPR by Transport Canada, and was directed to identify the severity of air temperature and wind speed in all parts of this area throughout the year. There is no specific requirement for use of such data in the selection of ship-hull steels in either the ASPPR or the rules of the various classification societies. However Lloyd's Register has published special requirements and appears to be developing rules that depend on "...the minimum design air temperature...obtained after the exclusion of all recorded values having a probability of occurrence of less than 3%, ...". The presented results therefore include temperatures and wind speeds that have been recorded at this and two other levels of probability.

Considering more severe conditions to include temperatures less than -30, -40, and -50°C, and temperatures less than -30 and -40°C combined with winds in excess of 50 km/h, an examination of the duration results confirms that conditions are generally more severe in the western portion of the Arctic. Based on the duration analysis and on the representative 3 percentile level temperatures, ASPPR zones 1 to 7 (excluding the two portions of zone 6 which lie to the eastward of longitude 95°W) would be classed as the most severe areas.

Records used to develop the results presented herein are, in many ways, incomplete. Anyone using the data as a basis for ship-hull steel selection is cautioned to take particular note of the limitations that are expressed for the benefit of users.

SOMMAIRE

Les navires destinés à la navigation dans l'Arctique canadien doivent être construits en matériaux dont les propriétés ne risquent pas d'être gravement altérées par les conditions atmosphériques régnant dans cette région du globe. Or, nombre des aciers utilisés en construction navale souffrent d'une fragilisation inacceptable aux basses températures, notamment en deçà d'un seuil critique. Donc, pour un choix judicieux des aciers à mettre en oeuvre, il est important de connaître les températures et les coefficients de transfert thermique auxquels la structure d'un navire risque d'être soumise dans les eaux arctiques où il sera appelé à naviguer.

Ce rapport présente une étude dont l'objectif était double, soit :

- dresser un tableau des températures de référence et des indices de refroidissement à prendre en compte pour la définition des critères de sélection des aciers destinés à la construction des navires devant évoluer dans les eaux arctiques canadiennes et qui sont par conséquent soumis aux dispositions du Règlement sur la prévention de la pollution des eaux arctiques par les navires (RPPEAN); et

- constituer une base de données météorologiques qui pourra servir lors d'études du même genre.

La présente étude a porté sur les diverses zones de navigation à accès réglementé par Transports Canada en vertu des dispositions du règlement précité; elle visait à déterminer la rigueur des conditions atmosphériques (températures de l'air et vitesses du vent) qui règnent dans cette région du globe à différentes époques de l'année. Ni le règlement précité ni ceux des diverses sociétés de classification n'assujettissent la sélection des aciers de coque à des critères de température d'emploi avec ou sans indice de refroidissement. Par contre, le Lloyd's Register of Shipping a publié des prescriptions particulières et élaborerait actuellement des règlements fondés "... sur la température de l'air minimum de référence (...) obtenue après exclusion de toutes les valeurs enregistrées dont la probabilité est inférieure à 3%, ...". Les résultats présentés dans cette étude comprennent donc les températures et vitesses du vent correspondant à ce niveau de probabilité ainsi qu'à deux autres.

Si l'on considère que les conditions extrêmes comprennent des températures inférieures à -30, -40 et -50°C ainsi que des températures inférieures à -30 et -40°C avec un vent dépassant 50 km/h, l'analyse qui vise à déterminer la durée des différentes conditions enregistrées permet d'affirmer que les conditions atmosphériques sont généralement plus rigoureuses dans la partie ouest de l'Arctique. En se fondant sur cette détermination et sur les niveaux de température représentatifs délimités par le troisième centile, on peut déduire que les zones 1 à 7 de la classification du RPPEAN (exclusion faite de deux secteurs de la zone 6, situés à l'est du méridien de longitude 95° ouest) seraient classées comme les plus défavorables.

Les relevés utilisés pour parvenir aux résultats présentés dans ce rapport sont incomplets à plusieurs titres. Quiconque voudrait s'en servir pour la sélection des aciers de coque aurait intérêt à prendre bonne note des réserves et mises en garde formulées.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. METHODOLOGY AND RESULTS 1

2.1 Data Sources 1
2.2 Initial Data Reduction 2
2.3 Identifying Atmospheric Environmental Zones 2
2.4 Duration Analysis 4
2.5 Extreme Low Temperature Analysis 4

3. DISCUSSION 5

3.1 Comparing "New" and "Old" Zones 5
3.2 Observations on the Recorded Temperature Levels 5
3.3 Choice of Basis for Ship-Hull Steel Selection 6

4. CONCLUSIONS 6

4.1 Value of the Results 6
4.2 Limitations on Value 6

5. RECOMMENDATIONS 8

5.1 For the Ship Designer 8
5.2 For the Ship Design Regulator 8

REFERENCES 39

APPENDIX

Air Temperature Charts

LIST OF FIGURES

Figure 1	Study Area, Existing Arctic Shipping Pollution Prevention Regulations (ASPPR) Zones and Observing Stations Used in this Study	9
Figure 2a	Determination of Temperatures not Exceeded for Specified Percentages of Time for the Month of January at Resolute A	10
Figure 2b	Determination of Wind Speeds Exceeded for Specified Percentages of Time for the Month of January at Resolute A	11
Figure 3	Preliminary Pattern of 21 Zones Found in this Study	12
Figure 4a – c	Minimum 1-Percentile Temperature Values for the Zones Shown in Figure 3	13–15
Figure 5	Final Map of Zones Based on Temperature and Wind Speed Considerations	16
Figure 6	Three-Percentile Values of High Cooling Rate Index (°C-km/h) for January	17

LIST OF TABLES

Table 1	Stations Used in This Study	18
Table 2a	Ten-Percentile Values of Low Temperature (°C)	19
Table 2b	Three-Percentile Values of Low Temperature (°C)	20
Table 2c	One-Percentile Values of ow Temperature (°C)	21
Table 2d	Ten-Percentile Values of High Wind Speed (km/h)	22
Table 2e	Three-Percentile Values of High Wind Speed (km/h)	23
Table 2f	One-Percentile Values of High Wind Speed (km/h)	24
Table 3	Representative Temperatures (°C) for Each of the 13 Zones	25
Table 4	Three-Percentile Values of High Cooling Index (°C–km/h)	26
Table 5	Observing Stations Used in the Duration Analysis for Each Zone	27
Table 6	Surface Air Temperature and Wind Speed Criteria Used in the Duration Analysis	28
Table 7 – 21	Monthly Duration of Table 6 Criteria for Each of the Zones in Figure 5	29–36
Table 22a	Expected Extreme Low Temperatures (°C) for Each Zone with 90-Percent Confidence Intervals (Annual Values)	37
Table 22b	Expected Extreme Low Temperatures (°C) for Each Zone with 90-Percent Confidence Intervals (Seasonal, July to October, Values)	38

1. INTRODUCTION

Many of the steels used in ship construction exhibit unacceptably brittle behaviour at temperatures below critical thresholds. It is important to know the temperatures to which a ship may be exposed when operating in arctic waters before selecting the steel for that ship.

This report describes a study with a twofold purpose:

- to prepare design temperature and cooling rate information that would be pertinent for selecting ship-hull steel criteria to be applied to vessels entering Canadian Arctic waters and thereby subject to the Arctic Shipping Pollution Prevention Regulations (ASPPR), and
- to provide a data base of weather information for possible future studies on this subject.

Canadian Arctic waters are defined by the ASPPR which divides those waters into shipping control zones, as shown in Figure 1, for its purposes (1). The present study is concerned with the severity of air temperature and wind speed in all parts of this area throughout the year.

No specific requirements have yet been set by the ASPPR or the various classification societies for the form or use of environmental data in the selection of ship-hull steels for low temperature service. However, Lloyd's Register appears to be developing rules that depend on "...the minimum design air temperature...obtained after the exclusion of all recorded values having a probability of occurrence of less than 3%, ..." (2). The collection and analysis of environmental data must, as a minimum, provide for this requirement.

2. METHODOLOGY AND RESULTS

2.1 Data Sources

Ideally, this study should have been based on comprehensive data collected offshore, and particularly in areas frequented by shipping over a significant period of years. Unfortunately, there has been no systematic offshore weather data collection. Instead, two sources were relied upon for this study as having the most relevant and reliable data available for the purpose.

2.1.1 Coastal Observing Stations

Thirty-two coastal observing stations scattered throughout the Canadian Arctic were chosen as the principal data sources. The set of stations used is listed in Table 1 and was selected with a view to having good geographical coverage of the study area and having produced continuous, homogeneous series of observations. The data used generally covered the period 1953-1976 as shown in Table 1.

2.1.2 Ships of Opportunity

For the July to October period, meteorological observations from ships of opportunity, collectively analyzed by geographical areas, were used to supplement the coastal station data. These marine data cover the 1947-1973 period but are fragmentary in nature and are suspected of having a fair weather bias.

2.2 Initial Data Reduction

Initial reduction of the data involved the following steps:

- Percentage probability matrices of ranges of air temperature and wind speed were obtained for each observing station for each month of the year, analyzed collectively over the periods of record.
- These percentages were then used to plot graphs of cumulative probability of air temperature and wind speed occurrence.
- From these graphs, 10, 3 and 1-percentile level values were obtained. That is, for temperature, the values which are not exceeded 10, 3 and 1 percent of the time and for wind speed the values which are exceeded 10, 3 and 1 percent of the time. Figures 2a and 2b illustrate this procedure for the month of January at Resolute. The monthly values for each percentile level for each station are tabulated in Tables 2a through 2f.

2.3 Identifying Atmospheric Environmental Zones

2.3.1 Temperature Zones

Temperature Zones were identified by plotting the percentile values on 36 maps, one for each of three percentiles for each month. The data on these maps were supplemented by some marine data for the months of July to October.

The 36 temperature maps were hand-analyzed. The results of this analysis for the 1 and 3-percentile levels are shown on the 24 maps in the Appendix.

Each of these maps was then overlain with an outline of the ASPPR Shipping Control Zones as shown on Figure 1. From this it was evident that the existing Shipping Control Zones did not adequately reflect the areal temperature patterns.

A preliminary outline of 21 new zones was developed, as shown in Figure 3, such that reasonably uniform temperature conditions exist within each zone while maintaining existing Shipping Control Zone boundaries wherever possible.

The choice of 21 zones suggested more temperature variation than actually existed between the temperature fields. The number of zones was therefore reduced to a more representative, and workable, number while still maintaining consistency with the general sea-ice conditions upon which the Shipping Control Zones are based. This was done by:

- examining the 1-percentile maps and selecting from each of the 21 zones the minimum temperature plotted to give annual profiles of month-to-month minimum 1-percentile values for each zone as shown in Figures 4a, 4b and 4c,
- where profiles of adjacent zones differed by 3°C or less for more than one month of the year, the zones were flagged for possible combining, and each such case was further examined to ensure that known mean sea-ice conditions were generally uniform over the zones in question, and
- the resulting 13 zones, as shown in Figure 5, were lettered A through M to avoid confusion with the Shipping Control Zones.

2.3.2 Wind Speed Zones

Wind Speed Zones were similarly identified by plotting the percentile values, resulting in a further 36 maps, again one for each of three percentiles for each month. The data on these maps were supplemented as well by some marine data for the months of July to October.

The thirteen temperature zones were then checked for consistency with the plotted wind speed data. These plotted maps of wind were not geographically analyzed as the local influences on the wind data at many of the stations were felt to preclude a useful analysis.

From an examination of the monthly 1-percentile maps it was possible to state generally that throughout the year the wind speed values were:

- highest (approximately 65 to 100 km/h) along the eastern Arctic coasts from Ellesmere to Baffin Islands and in the eastern half of Hudson Strait,
- more moderate (55 to 80 km/h) among the Arctic islands north of Parry Channel, west of Ellesmere and Devon Islands, and in the western Hudson Strait/northern Hudson Bay area, and
- lowest (45 to 70 km/h) in the area between Parry Channel and the mainland, westward from Foxe Basin.

It was observed that none of the 13 zones based on temperature conflicted with this general pattern of wind variation and so there was no need for further adjustment.

2.3.3 Cooling Index Zones

As a further consideration of wind effect, a Cooling Index, specified for this project by TDC, was used to give an indication of combined wind speed and temperature effects. The index was:

$I = -vT_{air}$ for $T_{air} \leq 0°C$, $v \geq 1$ km/h

$I = -T_{air}$ for $T_{air} \leq 0°C$, $v = 0$

$I = 0$ for $T_{air} > 0°C$, $v =$ any value

where I = Cooling Index

v = surface hourly wind speed (km/h)

T_{air} = surface air temperature (°C)

Again the local influences inherent in the wind data were a significant factor in the interpretation of the cooling index analysis and for that reason geographical analysis was treated with caution. Three-percentile point values for January (the index values exceeded 3 percent of the time) are shown in Figure 6 which suggested that the cooling index patterns would be reflected reasonably well by those of the air temperature over the study area for the same month. This was found to be true as well for the other months of the year. It was therefore concluded that the 13 temperature zone pattern of Figure 5 was reasonably consistent with the expected geographical variation in cooling index and that further modification was unnecessary.

2.3.4 Representative Zonal Values

For the 13 zones, a set of "representative" temperatures was tabulated for each percentile level for each month. These representative temperatures were taken to be the lowest analyzed values contained in each zone for the appropriate percentiles/months. The resulting values are given in Table 3. A presentation of such temperatures with a finer resolution than monthly was not felt to be neccessary.

Representative 3-percentile level values of the cooling index for each of the 13 zones were also determined by selecting the highest value in each zone. These are given in Table 4.

2.4 Duration Analysis

Stations within each of the zones were then selected for duration analysis. Generally, preference was given to hourly or 3-hourly observing stations, hourly readings being synthesized for the latter based on persistence. Six-hourly observing stations were included only where they were needed to ensure coverage of the entire zone in question. In some instances, no observing stations were located within a zone. In each such case, a station which was adjacent to the zone and considered representative was used. The selected stations are listed in Table 5.

The duration analysis procedure was generally as follows:

- Significant threshold values of air temperature and, based upon (3), combined conditions of air temperature and wind speed were selected and listed in Table 6.
- Durations were determined for air temperature less than the six threshold temperature values and for air temperature less and wind speed greater than the nine combined condition values.
- The maximum monthly duration for each of these 15 conditions in each zone was chosen to be the maximum observed amongst various stations selected for this analysis in respect of each zone. These values are tabulated in Tables 7 through 21, each of which relates to one of the Table 6 conditions.

2.5 Extreme Low Temperature Analysis

Based on the maximum durations for the six temperature threshold categories of Table 6, as recorded in Tables 7 through 12, a station considered to be representative of each of the thirteen zones was selected. For each of these stations, time series of annual and seasonal (July through October) extreme low temperatures were obtained. A Gumbel extreme value analysis (4) was then performed on each of these series and expected low temperatures for various return periods were derived. The results are shown in Table 22a, Annual, and 22b, Seasonal. 90% confidence levels for these expected temperatures are also shown in these tables.

3. DISCUSSION

3.1 Comparing "New" and "Old" Zones

The developed zones, as shown in Figure 5, differ somewhat from the ASPPR Shipping Control Zones of Figure 1. This is particularly true in the eastern Arctic where the new zones are meridionally oriented as distinct from the generally zonal nature of the ASPPR zones. The new pattern retains the sense of the general sea-ice conditions in that all the eastern zones are dominated by first year ice (moving pack in the winter and complete clearing in the summer on average). However, specific zones recognize variations in this regime, examples being:

- zone I which includes the area between Cape Hooper and Cape Dyer where sea-ice lingers throughout the summer in some years;
- zone J which delineates the core of the "North Water Polynya" where open water/thin ice can persist throughout the winter, and
- zone H which includes both first and multi-year ice in winter, some of which may be fed southward into zone I during the navigation season.

In the western Arctic, the new zones generally follow the old ones, except that

- the Queen Maud Golf and Committee Bay areas are now joined as zone E despite the tendency for old ice to linger in the latter area, and
- the northern half of Viscount Melville Sound has been combined with the waters to the south to form the new zone D.

3.2 Observations on the Recorded Temperature Levels

3.2.1 The 3-percentile Levels

The selection of ship-hull steel grades, as specified by Lloyd's Register of Shipping, depends on the assessment of a design temperature (2). This is taken to be the lowest temperature obtained after the exclusion of all values having a probability of occurrence of less than 3%. These temperatures correspond to the 3-percentile level in Table 3. The following are some observations on this 3-percentile level.

- The lowest value at this level is -49°C for Zone A in February.
- For all zones, February is the coldest month although conditions do not vary from it more than 5°C at the 3% level during the December to March period.
- A threshold value of -40°C is not exceeded
  - in zone A from November to April
  - in zones B to G from December to March, and
  - in zones H and I from January to March.
- For zone M, the least severe of the zones in terms of temperature, a 3-percentile value of approximately -30°C occurs from December to March.
- The maximum 3-percentile value obtained is 0°C for zone L in August.

3.2.2 Environmental Severity

Considering more severe conditions to include temperatures less than -30, -40, and -50°C, and temperatures less than -30 and -40°C with winds in excess of 50 km/h, an examination of the duration results confirms that conditions are generally more severe in the western portion of the Arctic. Within the total area considered, zones A to G experience the longest durations of these air temperature and combined temperature and wind speed conditions. Based on the duration analysis and on the representative 3-percentile level temperatures discussed in the previous section, zones A, B, D and E would be classed as the most severe areas.

3.3 Choice of Basis for Ship-Hull Steel Selection

Transport Canada has identified certain Arctic priority areas such as the Beaufort Sea, the Parry Channel — Prince of Wales Strait route, and the Queens Channel — Prince Philip Basin route. It will be noted that zones A, B, D and E, which were classed as the most severe in the previous section, impact on these routes either directly or, for the Beaufort Sea, as approach zones. Thus ships expected to use either of these routes are likely to be subject to the most stringent design criteria identified for Arctic operations.

4. CONCLUSIONS

4.1 Value of the Results

The results presented in this report are the best measures of atmospheric environmental severity in the Canadian Arctic that can be derived from available records of air temperature and wind speed. They can be taken as reasonable indicators of relative severity in the various areas of the Canadian Arctic, but may not truly represent the most severe conditions that can occur. Anyone using these results should be aware of the limitations in the following section.

4.2 Limitations on Value

4.2.1 General

The accuracy of the results presented in this report is limited by a number of factors, the major ones being:

- the fragmentary data from marine areas;
- the incomplete spacial and temporal coverage provided by the coastal stations that were available and used; and
- the question of the impact of climatic change on the validity of the data base used to compute the presented results.

4.2.2 Lack of Marine Data

The paucity of marine data was pointed out at the beginning of this report. The data that are available to supplement those from the coastal stations are only from the July to October annual navigation season and are fragmentary in areal coverage. They were used with caution in developing the presented results.

4.2.3 Coastal Station Coverage

The available network of coastal observing stations suffers from gaps in coverage over the area of interest, particularly in the Victoria — Prince of Wales Islands and the Devon — Ellesmere Islands area. Other problems in using the data from these stations included:

- some stations have only short-term records, such as Coburg Island (1972-1974) and Johnson Point (1972-1976);
- some stations have good periods of records which do not coincide exactly with those of most of the stations used, e.g. Resolution Island (1930-1960 as compared with the 1953-1976 period generally available);
- differing observing programs — hourly vs. 3 hourly vs. 6 hourly; and
- varying station elevations.

Adjustments for these variations were not generally made in preparing the temperature map analyses, except that data from short-term stations were treated with caution. On the other hand, it was felt that detailed attention to making adjustments for such deficiences would not have resulted in significant differences in the pattern of zones which was developed.

4.2.4 Impact of Climatic Change

The validity of the results presented in this report rests on the historical data available. Any variations or trends in climate that would be of sufficient magnitude to make the historic period significantly unrepresentative of the future would require a reassessment of the pattern of zones arrived at here. The best currently available information indicates a gradual global warming trend into the next century. This will be most strongly felt in the Arctic, particularly during the winter months. It is likely to decrease the severity of temperature conditions discussed in this report. The potential effect on the wind regime, and hence combined wind-temperature conditions, is less clear. Shorter term variations within this overall trend could produce either cooler or warmer conditions.

5. RECOMMENDATIONS

5.1 For the Ship Designer

The study reported herein was undertaken to provide the ship designer with atmospheric environmental data for use in responding to probable future regulatory requirements of classification societies, and/or Transport Canada, in the selection of ship-hull steel for service in the Canadian Arctic. A variety of such data has been developed which relates to specific geographical areas, times of the year and probability of occurrence. The designer may be guided in the use of this data by the zonal and seasonal requirements for operation of the intended vessel in the Canadian Arctic and by the limitations on use of this data which are summarized in the preceding section.

5.2 For the Ship Design Regulator

The results presented herein have been derived for both the designer and the regulator. The limitations expressed in the previous part apply equally to both users. The regulator who strives to improve on the quality of information available will consider improving on these results by taking further action such as the following.

5.2.1 Improving Data from Marine Areas

There are two possibilities:

- Gridded surface temperature data are available from the Fleet Numerical Oceanographic Centre in the United States. These are based on objectively analyzed synoptic charts of the Northern Hemisphere, although only from approximately a 10-year period. Use of this material might enhance the subjective approach used in the present study.

- A more involved approach would be to abstract surface temperatures over marine areas from satellite-derived radiance values. If good data can be obtained from this approach, this should result in a more reliable zonal analysis for the Canadian Arctic Archipelago than was possible using only coastal data.

5.2.2 Improving Duration Analysis

The duration analyses presented in this report were somewhat limited by the in-house computer program from which they were derived. Specifically, durations extending from one month into the next could only be determined for less than 1000 hour totals. As a result, the maximum durations given here were restricted to only the maximum number of hours in the particular month. Further program work to overcome this problem and also to give annual extreme durations to allow return period analyses would be useful.

Duration analyses based on the gridded temperature data referred to in the previous subsection would also be useful.

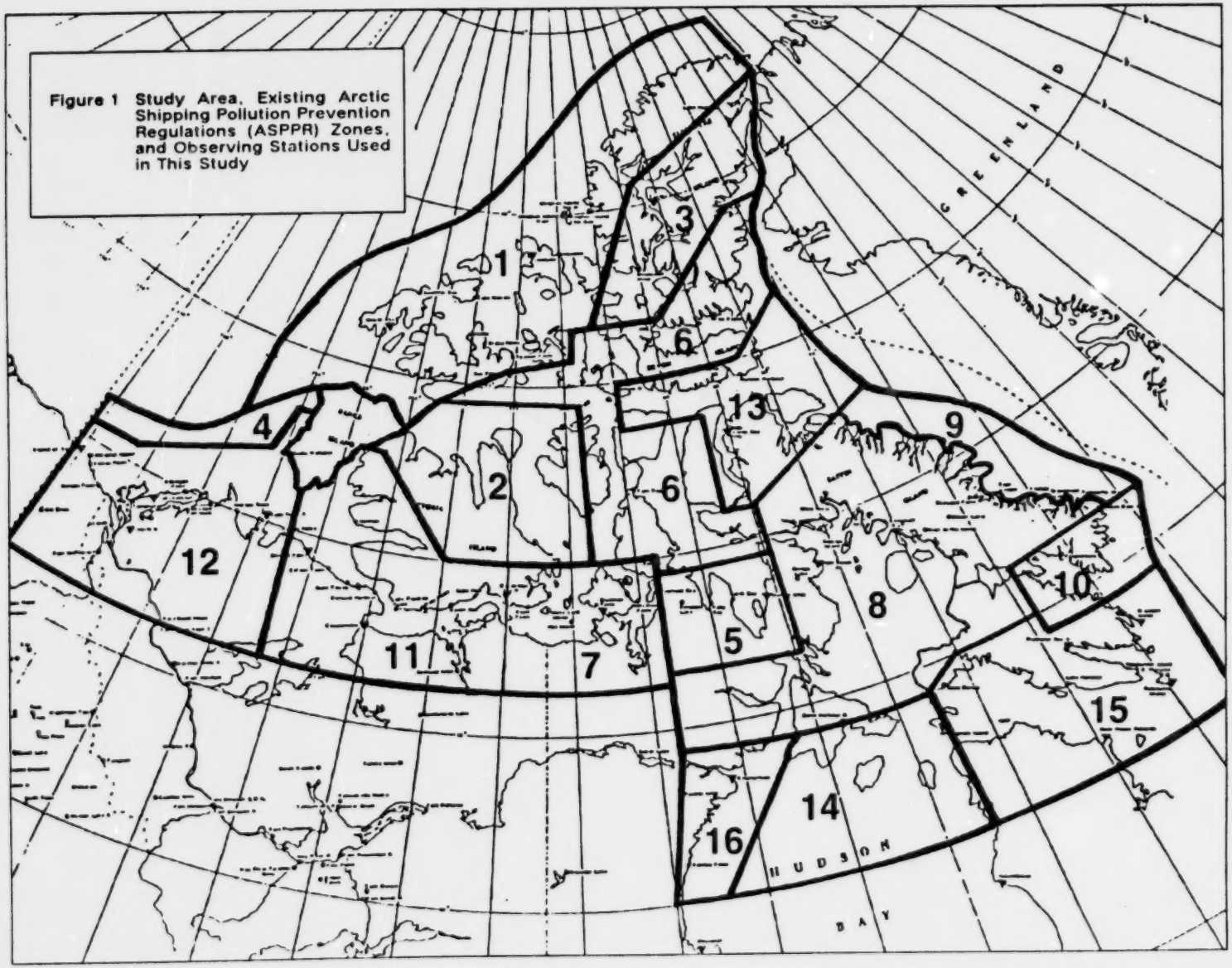


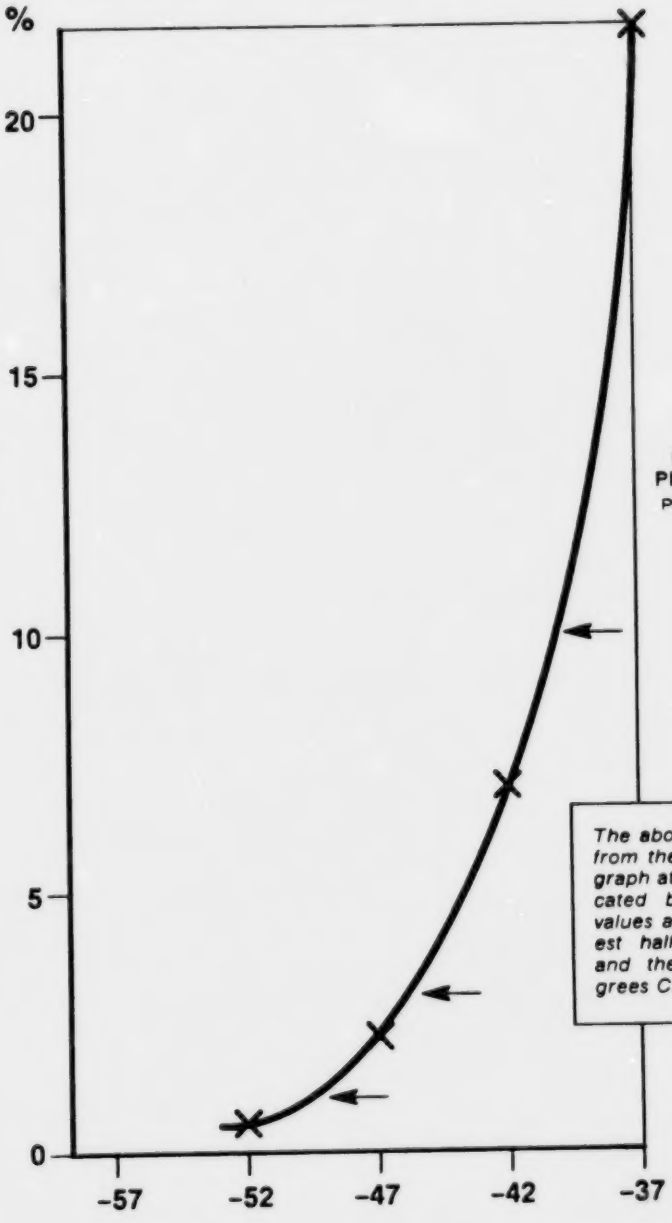
Figure 1 Study Area, Existing Arctic Shipping Pollution Prevention Regulations (ASPPR) Zones, and Observing Stations Used in This Study

Figure 2a. Determination of Temperatures not Exceeded for Specified Percentages of Time for the Month of January at Resolute A.

FROM RESOLUTE A JANUARY OBSERVATIONS (1953-1976)

TEMPERATURE NOT EXCEEDED (°F)	PERCENTAGE OF TIME
-52	0.3
-47	2.4
-42	7.2
-37	21.5
-32	39.9

Data above plotted on graph at right at the points marked "X".

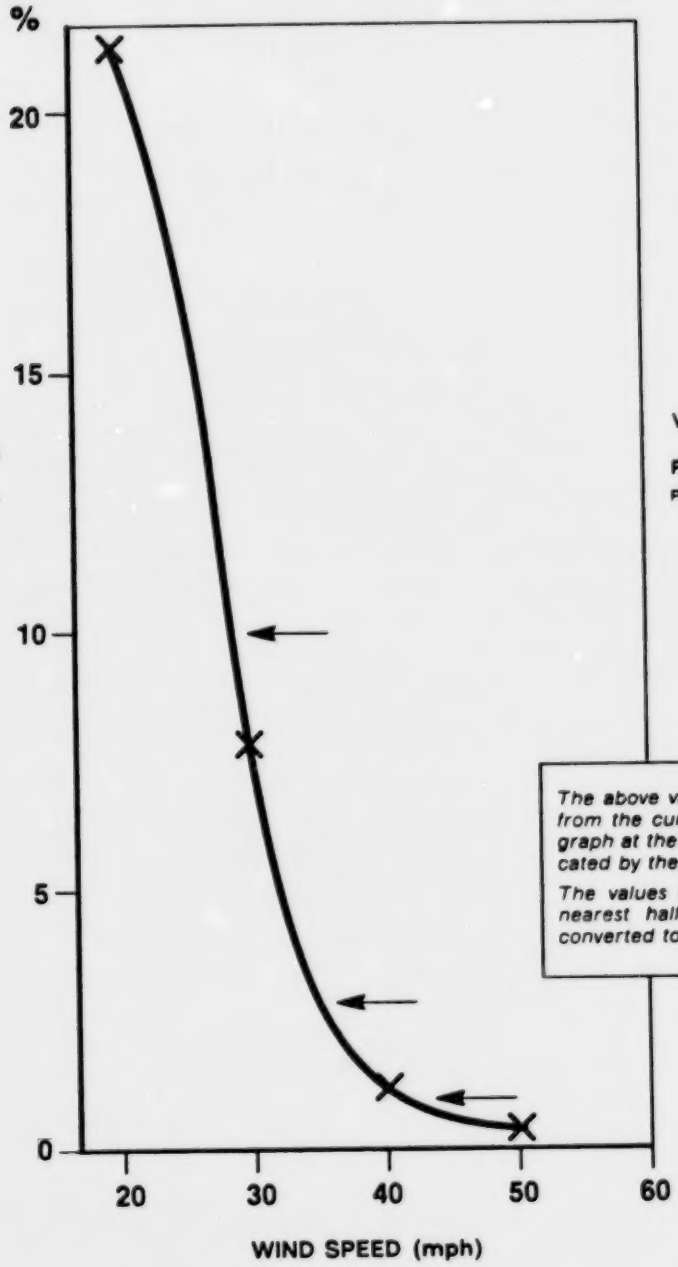


TEMPERATURE NOT EXCEEDED FOR THE FOLLOWING PERCENTAGES OF TIME:

PERCENTAGE OF TIME	TEMPERATURE NOT EXCEEDED (°F)	(°C)
10	-40.5	-40.3
3	-46.0	-43.3
1	-50.0	-45.6

The above values are derived from the curve drawn on the graph at the left and are indicated by the arrows. The values are taken to the nearest half degree Fahrenheit and then converted to degrees Celsius.

Figure 2b. Determination of Wind Speeds Exceeded for Specified Percentages of Time for the Month of January at Resolute A.



FROM RESOLUTE A JANUARY OBSERVATIONS (1953-1976)

WIND SPEED EXCEEDED (mph)	PERCENTAGE OF TIME
60	0.02
50	0.2
40	1.4
30	8.1
20	21.9
10	51.4

Data above plotted on graph at right at the points marked "X".

WIND SPEED EXCEEDED FOR THE FOLLOWING PERCENTAGES OF TIME:

PERCENTAGE OF TIME	WIND SPEED EXCEEDED (mph)	(km/h)
10	28.5	46
3	36.0	58
1	42.0	68

The above values are derived from the curve drawn on the graph at the left and are indicated by the arrows.

The values are taken to the nearest half mph and then converted to km/h.

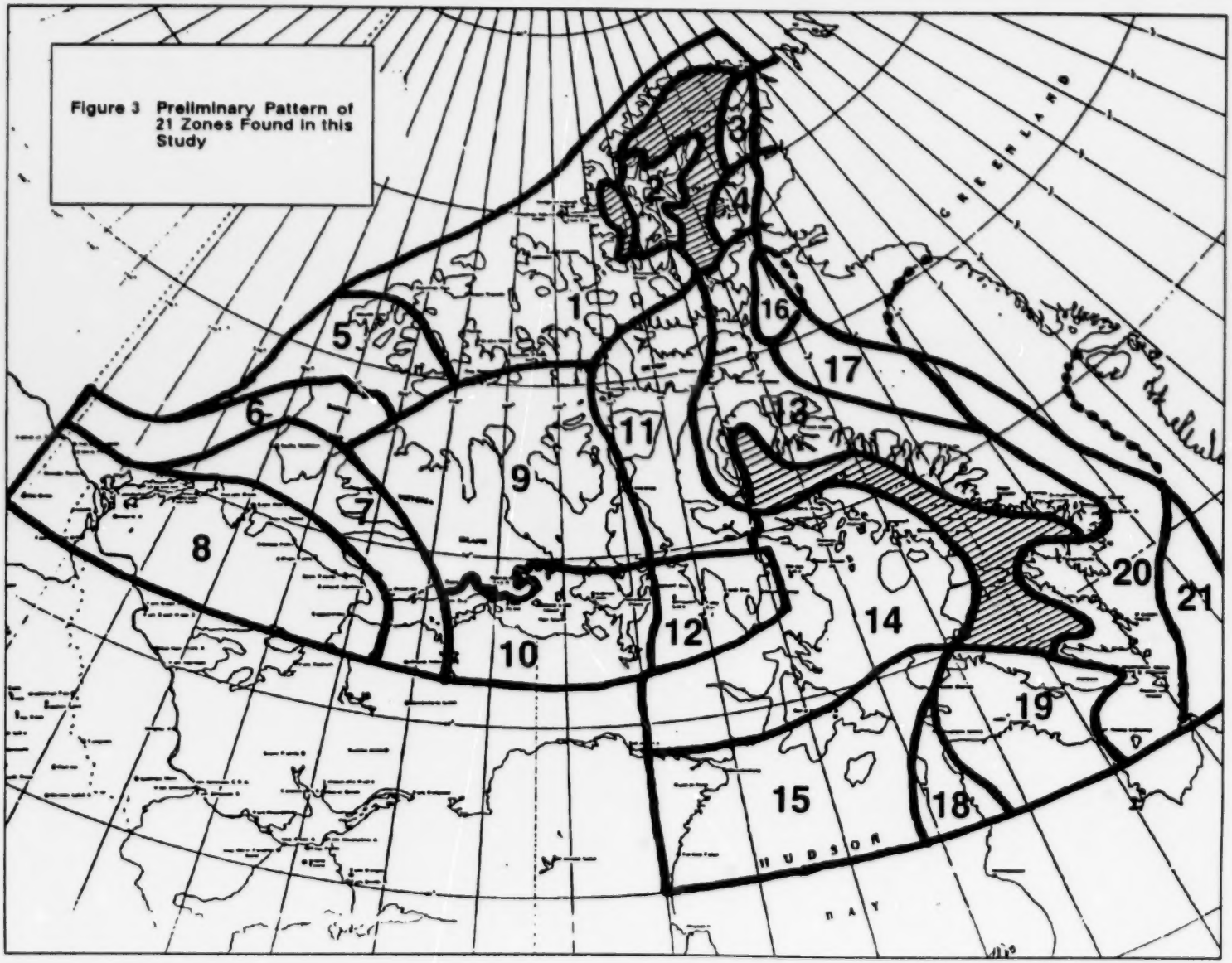


Figure 3 Preliminary Pattern of 21 Zones Found in this Study

Figure 4a. Minimum 1-Percentile Temperature Values for the Zones Shown in Figure 3.

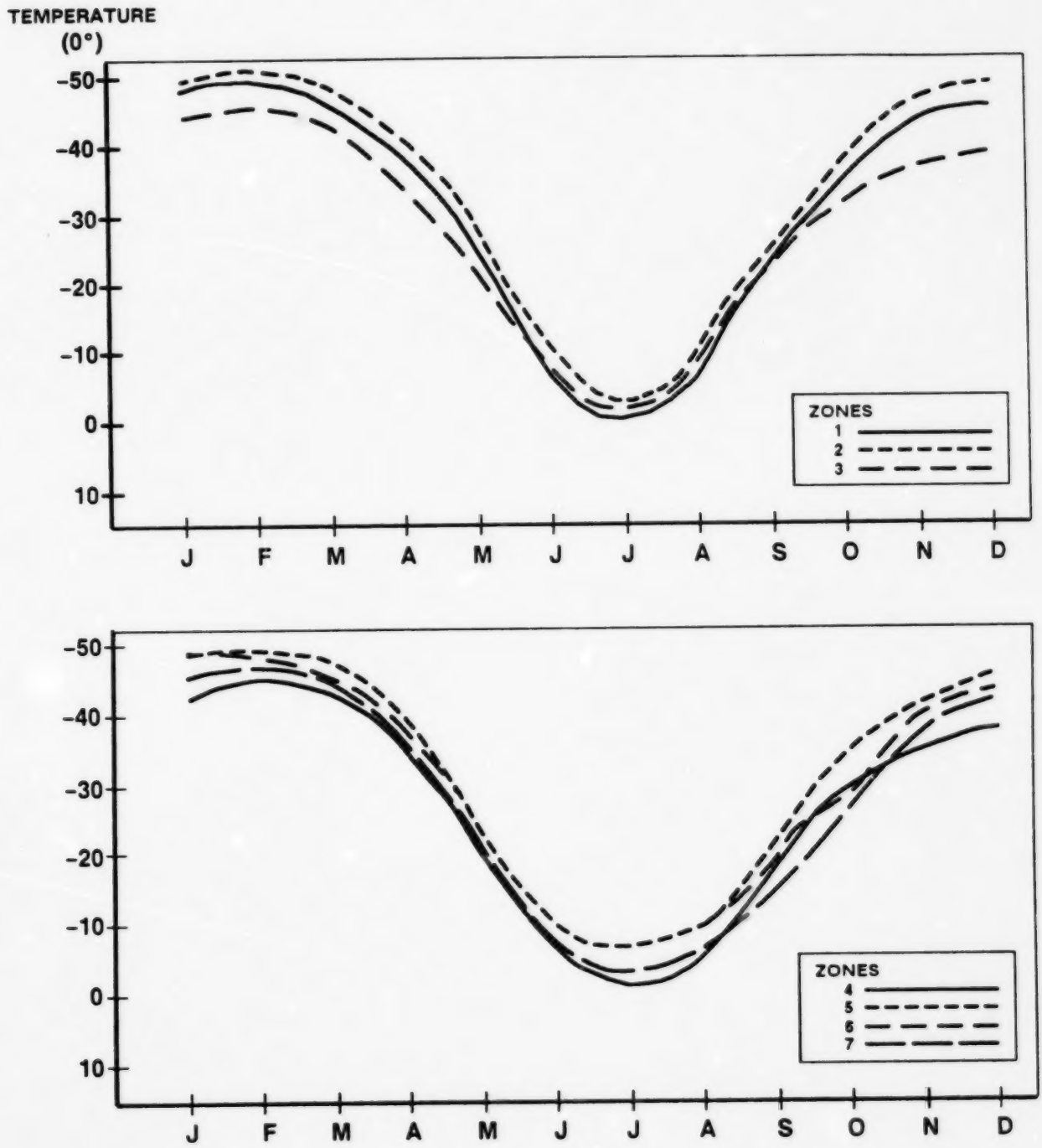


Figure 4b. Minimum 1-Percentile Temperature Values for the Zones Shown in Figure 3.

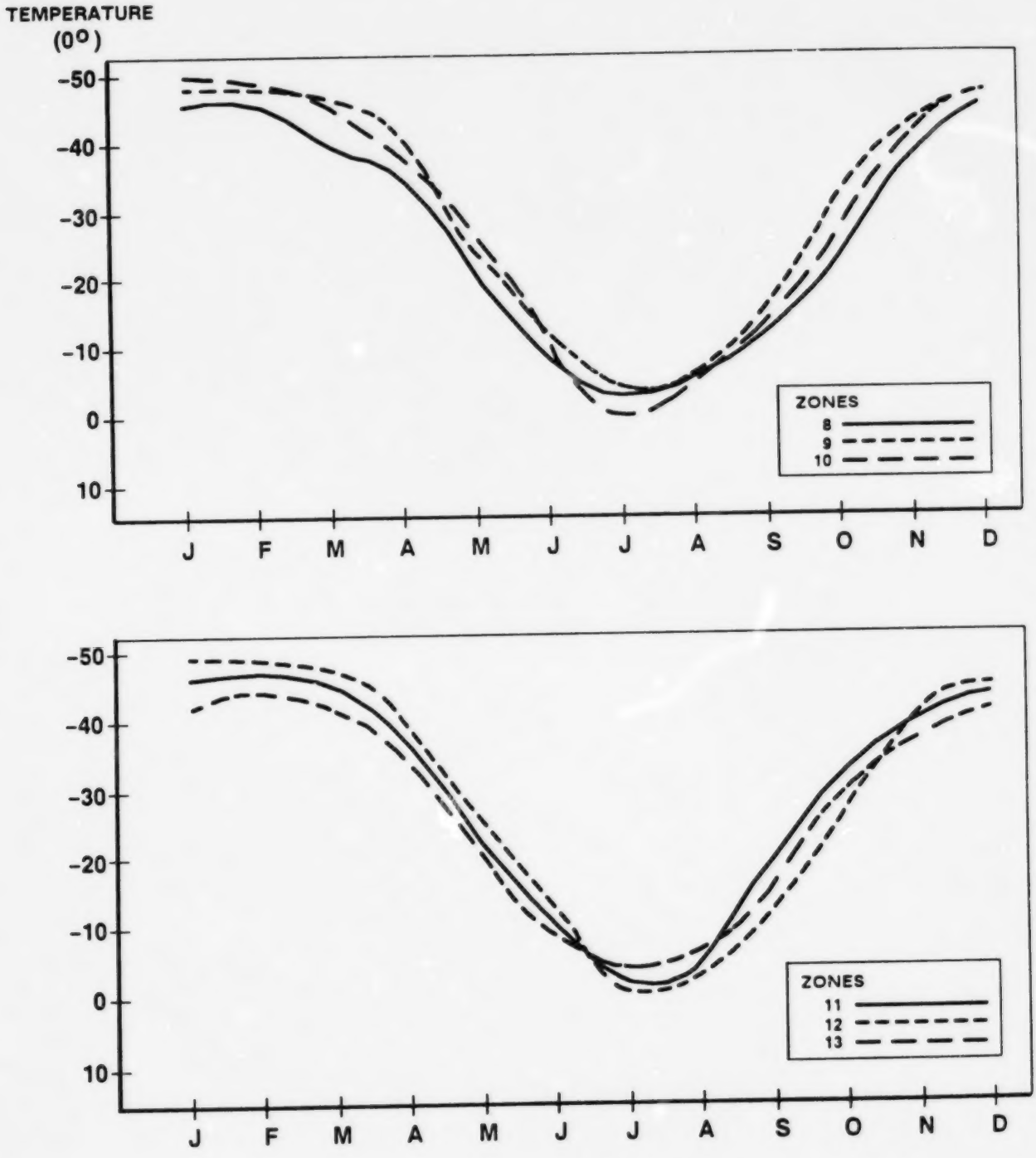
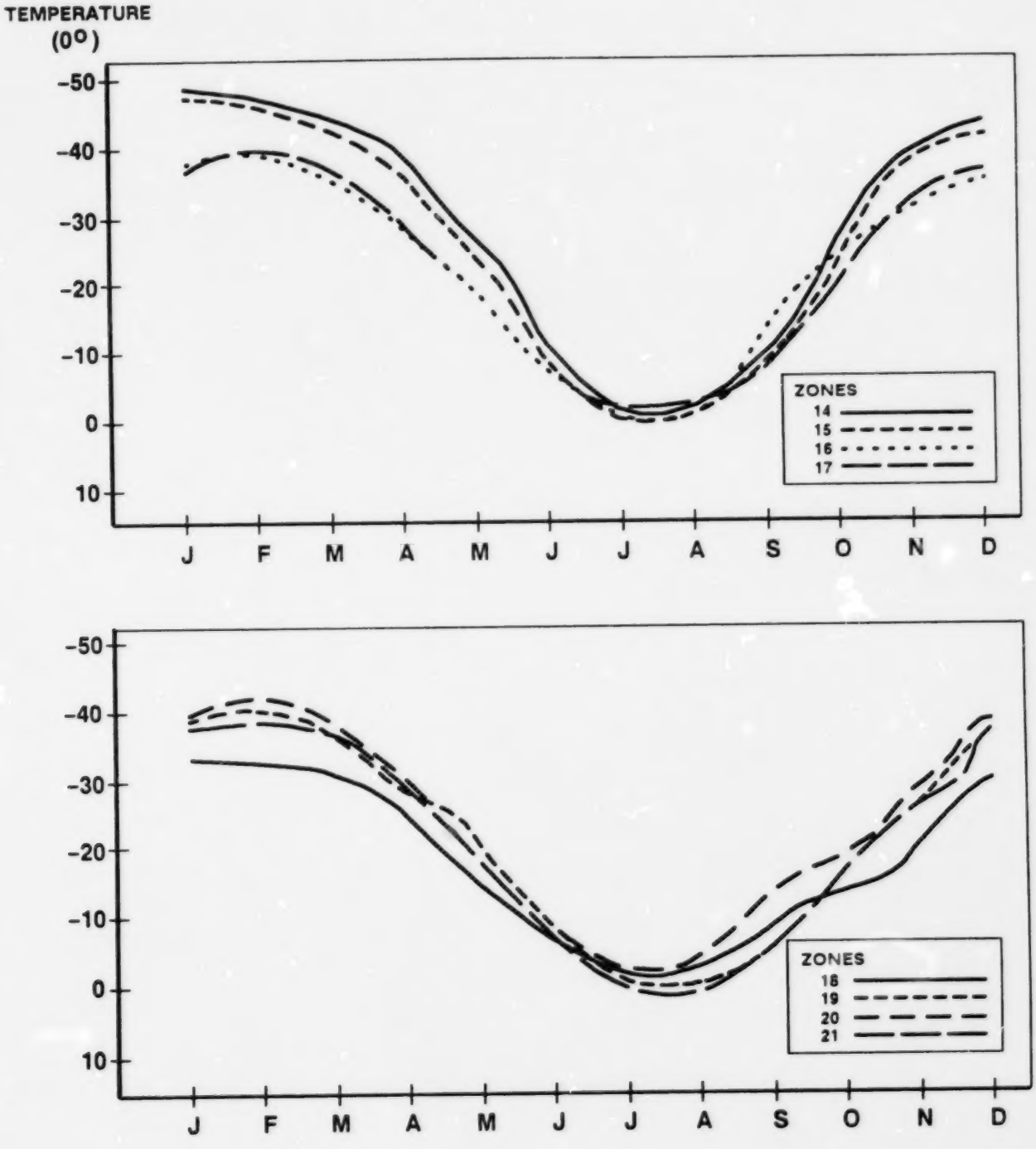


Figure 4c. Minimum 1-Percentile Temperature Values for the Zones Shown in Figure 3.



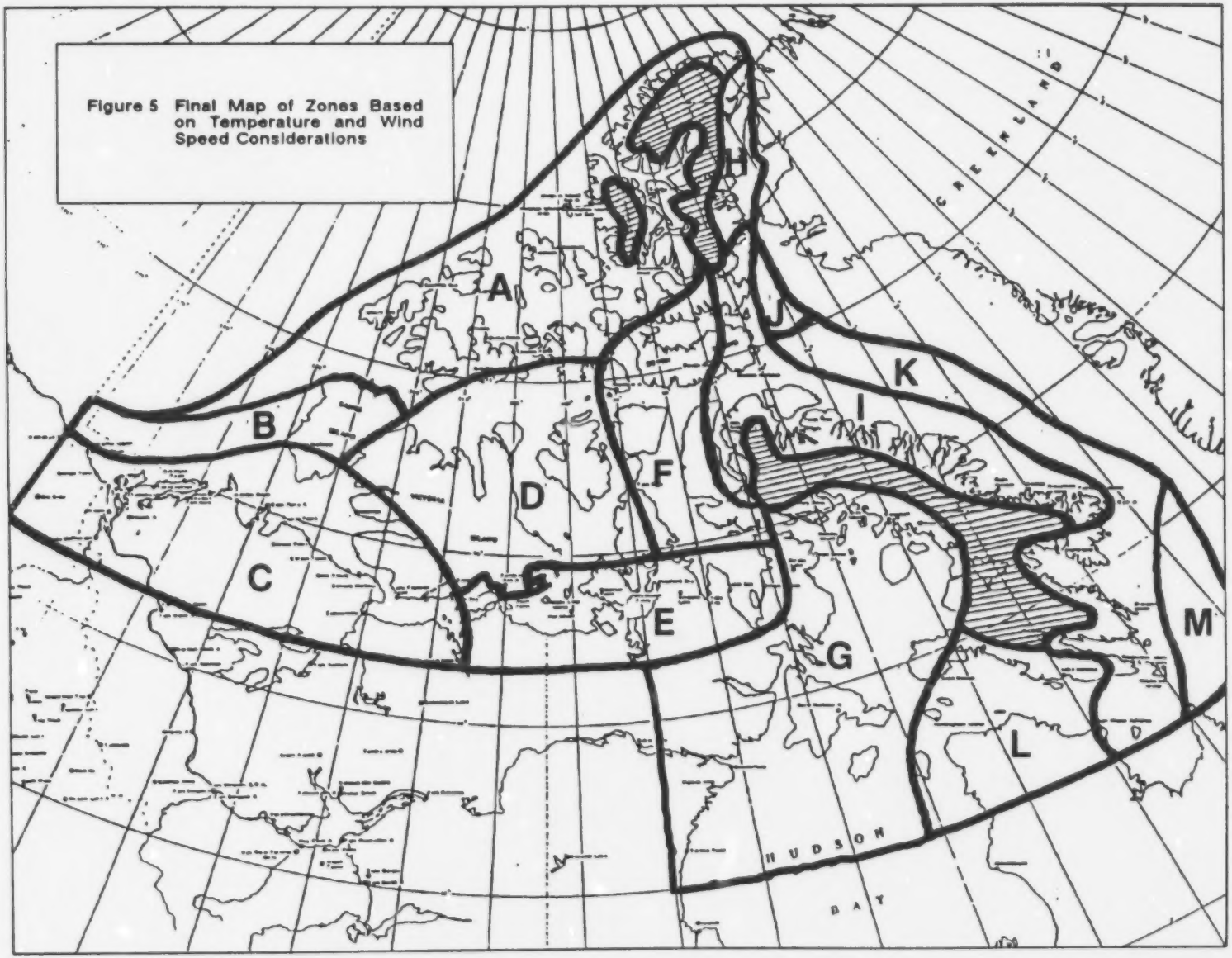


Figure 5 Final Map of Zones Based on Temperature and Wind Speed Considerations

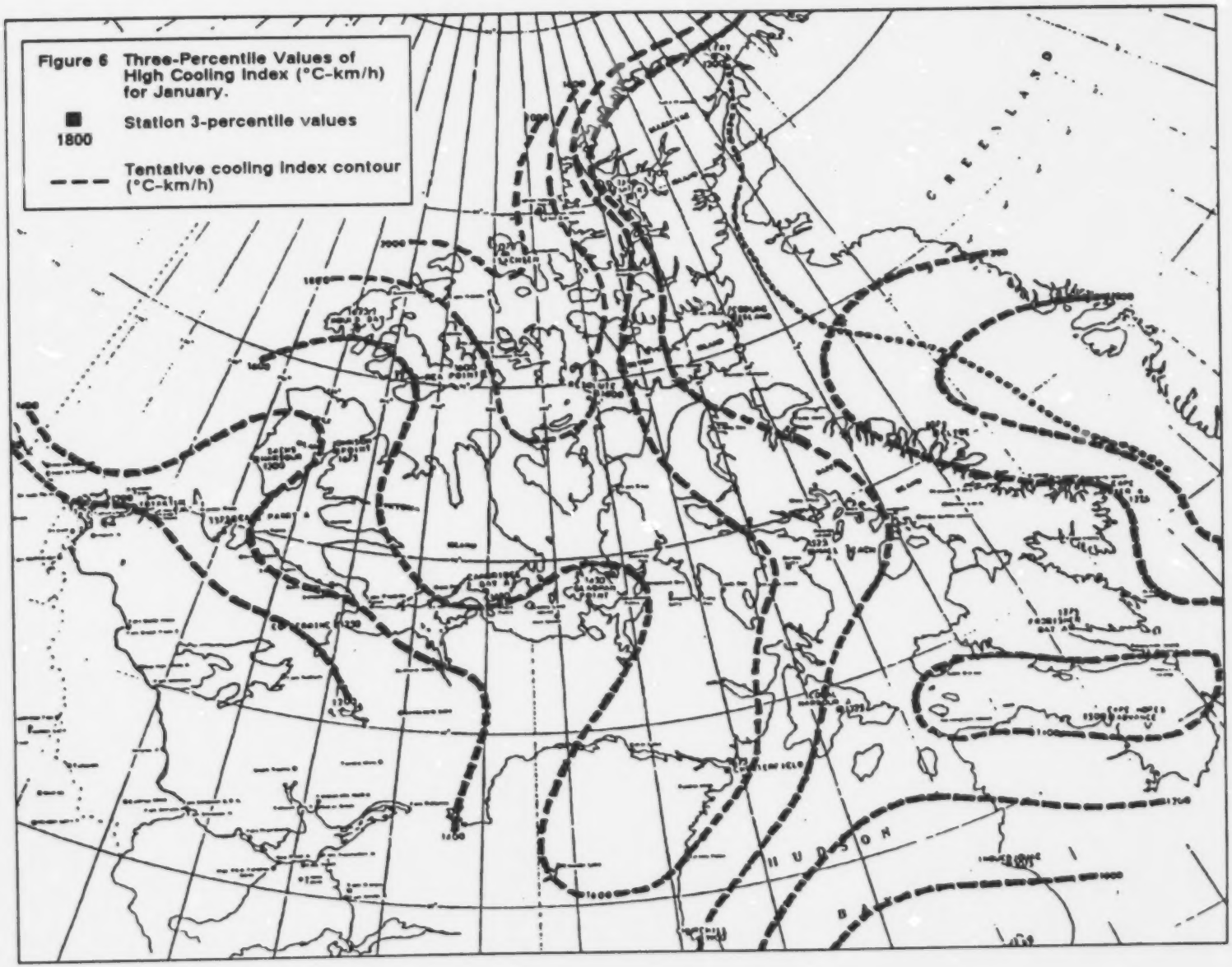


Figure 6 Three-Percentile Values of High Cooling Index (°C-km/h) for January.
Station 3-percentile values
1800
Tentative cooling index contour (°C-km/h)
GREENLAND
HUDSON

Table 1

Stations Used in This Study

Station	Period of Record*	Station	Period of Record*	Station	Period of Record*
Northwest Territories		Northwest Territories		Northwest Territories	
Alert	1953–1976	Coral Harbour A	1953–1976	Resolute A	1953–1976
Arctic Bay	1953–1964, 1971–1976	Eureka	1953–1976	Resolution Island	1953–1961
Brevoort Island	1960–1975	Frobisher Bay A	1953–1976	Sachs Harbour	1955–1976
Cambridge Bay A	1953–1976	Gladman Point	1957–1976	Tuktoyaktuk	1958–1976
Cape Dyer A	1959–1976	Hall Beach A	1956–1976		
Cape Hooper	1956–1976	Isachsen	1953–1976	Yukon Territory	
Cape Parry A	1957–1976	Johnson Point	1972–1976		
Chesterfield	1953–1976	Longstaff Bluff	1957–1976	Komakuk Beach	1973–1976
Clinton Point	1958–1976	Mackar Inlet	1957–1976		
Clyde	1953–1976	Mould Bay	1953–1976	Manitoba	
Coburg Island	1972–1974	Nottingham Island	1953–1970		
Coppermine	1953–1976	Rea Point A	1969–1976	Churchill A	1953–1976
				Québec	
				Cape Hopes Advance	1953–1971
				Inoucdjouac	1953–1976

* *These are the periods of record used for the temperature/wind frequency and duration analyses. The Gumbel analyses of extreme low temperature were based on all observations since the stations' installation. For exemple, the period of record used for Nottingham Island for frequency and duration analyses was 1953-1970, but for extreme low temperature it was 1930-1970. The current AES archive on magnetic tape contains hourly data only from 1953.*

Table 2a

Ten-Percentile Values of Low Temperature (°C)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Alert	-39.4	-40.3	-39.7	-33.3	-19.7	-6.4	-0.3	-3.9	-17.5	-26.9	-33.3	-37.2
Arctic Bay	-37.8	-38.3	-37.8	-29.2	-15.3	-2.5	1.7	1.1	-6.4	-20.0	-30.0	-36.7
Brevoort Island	-30.3	-30.0	-28.6	-20.6	-10.8	-4.2	-1.1	-0.6	-4.4	-9.7	-17.5	-26.4
Cambridge Bay A	-42.2	-42.2	-39.2	-31.9	-18.6	-4.7	3.3	1.7	-6.1	-21.1	-33.3	-38.6
Cape Dyer A	-33.3	-32.8	-32.2	-23.1	-11.7	-3.9	0.6	-0.6	-5.8	-12.8	-22.8	-30.3
Cape Hooper	-33.9	-32.8	-31.7	-23.3	-14.2	-4.7	-1.7	-1.9	-5.6	-13.3	-23.6	-30.3
Cape Hopes Advance	-29.4	-30.8	-26.4	-18.9	-8.6	-1.9	0.6	1.4	-1.1	-5.3	-15.0	-23.9
Cape Parry A	-37.2	-38.3	-35.0	-27.8	-13.9	-2.2	1.1	0.6	-3.6	-14.7	-27.2	-33.1
Chesterfield	-41.4	-40.8	-37.2	-26.9	-14.4	-1.9	3.3	4.2	-2.5	-13.1	-28.9	-37.5
Churchill A	-36.7	-34.4	-30.3	-20.6	-9.4	-0.8	4.2	5.8	0.0	-7.8	-22.2	-32.2
Clinton Point	-35.8	-36.1	-33.3	-26.4	-13.1	-2.2	1.7	0.8	-4.4	-14.4	-26.1	-31.9
Clyde	-35.6	-36.1	-34.2	-26.1	-13.9	-3.3	0.3	0.0	-3.9	-12.5	-26.1	-32.5
Coburg Island	-31.7	-33.6	-31.4	-25.0	-13.3	-5.3	0.0	0.8	-7.5	-18.3	-26.1	-32.2
Coppermine	-39.2	-39.7	-35.8	-28.3	-13.6	-1.7	4.4	3.3	-3.1	-14.4	-29.2	-35.8
Coral Harbour A	-40.0	-39.4	-35.3	-26.1	-13.9	-3.1	3.9	2.8	-4.2	-16.1	-28.3	-35.8
Eureka	-45.6	-45.6	-45.0	-37.2	-20.0	-3.3	1.4	-0.6	-17.2	-31.4	-40.3	-43.3
Frobisher Bay A	-36.7	-36.1	-33.3	-24.2	-9.7	-0.8	2.5	2.8	-1.9	-12.2	-23.3	-32.5
Gladman Point	-44.2	-43.3	-39.7	-31.4	-19.2	-5.0	2.2	0.6	-6.4	-20.3	-33.6	-38.9
Hall Beach A	-41.4	-41.4	-39.7	-30.3	-16.7	-4.4	1.4	1.1	-4.7	-19.7	-32.2	-37.5
Inoucdjouac	-33.9	-33.9	-30.6	-20.8	-8.3	-1.4	3.6	4.2	1.1	-5.3	-14.4	-28.9
Isachsen	-43.9	-43.9	-42.5	-34.4	-19.4	-6.7	-1.1	-3.3	-16.1	-28.1	-36.7	-41.1
Johnson Point	-41.9	-39.4	-39.2	-29.2	-16.7	-4.4	1.4	-0.8	-11.1	-23.9	-31.7	-37.2
Komakuk Beach	-36.9	-39.4	-33.3	-26.9	-12.5	-1.9	0.8	0.6	-4.7	-19.2	-28.9	-36.4
Longstaff Bluff	-39.7	-38.9	-35.6	-26.4	-15.6	-4.2	1.4	0.3	-5.3	-18.1	-28.6	-34.2
Mackar Inlet	-42.2	-40.6	-37.8	-29.7	-17.5	-6.4	0.0	-1.7	-8.9	-20.0	-32.2	-36.9
Mould Bay	-41.7	-42.5	-40.6	-32.2	-18.3	-5.8	-0.6	-2.2	-13.1	-26.1	-34.2	-39.4
Nottingham Island	-31.9	-32.5	-29.4	-21.4	-10.0	-1.4	1.9	2.2	-1.4	-8.1	-19.2	-26.9
Rea Point A	-42.8	-40.6	-40.0	-32.8	-18.9	-6.9	0.6	-1.9	-12.2	-24.2	-33.1	-38.6
Resolute A	-40.3	-40.6	-39.2	-32.2	-18.9	-6.7	-0.6	-1.9	-10.8	-23.1	-33.3	-36.9
Resolution Island	-26.4	-25.8	-22.2	-15.6	-7.8	-2.2	0.0	0.8	-1.4	-5.6	-11.1	-20.0
Sachs Harbour	-41.1	-39.7	-37.2	-28.9	-15.6	-3.3	-0.3	-1.4	-7.5	-20.3	-30.3	-36.4
Tuktoyaktuk	-43.3	-39.4	-34.4	-27.5	-12.8	-1.7	3.6	2.8	-2.8	-15.8	-30.3	-34.7

Table 2b

Three-Percentile Values of Low Temperature (°C)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Alert	-41.7	-42.8	-42.8	-36.4	-22.2	-8.6	-1.1	-6.4	-20.6	-29.7	-35.8	-39.2
Arctic Bay	-40.0	-41.4	-40.6	-32.8	-18.6	-4.7	0.6	-0.6	-8.6	-23.3	-32.2	-39.4
Brevoort Island	-31.9	-32.5	-31.1	-23.6	-13.6	-5.3	-1.7	-1.1	-5.8	-12.8	-20.6	-29.2
Cambridge Bay A	-44.7	-45.0	-41.9	-35.0	-22.8	-7.8	1.9	0.3	-9.4	-25.0	-36.1	-41.1
Cape Dyer A	-37.8	-36.7	-35.6	-26.4	-16.1	-5.0	-1.1	-1.7	-8.9	-17.2	-27.2	-35.0
Cape Hooper	-36.4	-35.0	-34.2	-26.4	-16.9	-6.7	-2.8	-2.5	-7.8	-17.2	-26.7	-32.8
Cape Hopes Advance	-32.5	-33.6	-29.7	-22.5	-11.1	-3.6	-1.1	0.8	-1.9	-7.5	-17.5	-27.8
Cape Parry A	-40.0	-40.3	-37.5	-30.8	-18.1	-5.0	-0.6	-1.1	-6.1	-18.1	-30.6	-36.1
Chesterfield	-43.9	-43.3	-40.3	-30.3	-19.4	-4.2	1.9	3.3	-5.3	-18.1	-33.3	-39.4
Churchill A	-39.2	-37.8	-33.3	-24.4	-13.3	-1.9	1.7	3.9	-1.9	-12.2	-27.5	-35.0
Clinton Point	-38.9	-39.7	-35.6	-29.4	-17.2	-5.0	0.6	-0.6	-6.9	-17.8	-28.6	-34.7
Clyde	-38.3	-39.2	-37.2	-28.9	-18.3	-5.0	-1.4	-1.7	-6.1	-16.9	-28.9	-35.0
Coburg Island	-33.1	-35.6	-33.9	-26.9	-16.7	-7.8	-1.7	0.0	-10.0	-21.9	-29.4	-34.7
Coppermine	-42.2	-43.1	-38.6	-31.4	-17.8	-5.0	3.3	1.7	-6.1	-19.4	-32.2	-38.6
Coral Harbour A	-43.3	-42.2	-38.6	-30.0	-18.3	-5.6	1.4	0.8	-6.7	-20.8	-32.5	-38.9
Eureka	-47.8	-48.3	-47.2	-40.0	-23.3	-6.4	0.8	-2.8	-21.7	-35.3	-42.8	-46.1
Frobisher Bay A	-39.4	-38.6	-36.7	-27.2	-13.3	-2.8	1.7	1.7	-3.9	-16.7	-27.5	-36.4
Gladman Point	-46.4	-45.8	-42.8	-35.0	-22.8	-7.8	0.8	-1.1	-9.2	-23.9	-37.2	-41.7
Hall Beach A	-43.9	-43.6	-43.1	-33.6	-21.7	-8.1	0.6	0.0	-7.2	-24.2	-35.0	-40.0
Inoucdjouac	-36.9	-36.4	-33.9	-25.0	-10.8	-2.8	1.7	3.3	0.3	-7.8	-18.9	-32.8
Isachsen	-45.8	-46.7	-45.7	-37.2	-22.5	-8.9	-1.9	-5.3	-20.0	-31.7	-40.0	-44.2
Johnson Point	-43.9	-41.1	-41.7	-31.7	-19.7	-9.4	0.6	-1.9	-14.2	-27.2	-36.1	-39.7
Komakuk Beach	-42.8	-41.1	-36.9	-30.0	-17.8	-4.4	-1.1	-1.4	-8.9	-22.2	-31.9	-39.4
Longstaff Bluff	-43.3	-40.8	-39.2	-29.7	-19.2	-6.4	-0.8	-1.4	-7.2	-21.4	-32.8	-37.8
Mackar Inlet	-45.8	-43.3	-41.1	-32.8	-20.6	-9.4	-1.4	-3.3	-10.8	-24.4	-35.6	-39.7
Mould Bay	-44.7	-45.3	-43.6	-35.3	-21.1	-8.3	-1.7	-4.2	-17.2	-29.2	-37.2	-41.7
Nottingham Island	-34.2	-34.7	-32.2	-25.0	-12.8	-3.6	1.1	1.1	-3.1	-12.2	-22.2	-29.7
Rea Point A	-46.1	-42.2	-43.3	-35.8	-21.9	-10.0	-1.4	-3.6	-15.6	-26.4	-36.1	-40.6
Resolute A	-43.3	-43.3	-42.2	-34.7	-21.7	-9.4	-1.7	-3.6	-14.2	-26.7	-36.4	-39.4
Resolution Island	-30.0	-28.3	-25.0	-18.3	-9.4	-3.9	-1.7	-0.8	-1.9	-7.8	-13.3	-22.5
Sachs Harbour	-43.6	-42.5	-40.0	-32.8	-18.9	-6.1	-1.7	-2.5	-12.8	-23.9	-33.9	-39.7
Tuktoyaktuk	-41.7	-41.1	-37.5	-31.1	-17.2	-3.9	1.4	1.4	-5.6	-20.0	-33.6	-38.3

Table 2c

One-Percentile Values of Low Temperature (°C)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Alert	-43.6	-44.4	-44.4	-37.8	-23.9	-10.0	-1.9	-7.2	-22.8	-31.7	-37.8	-40.6
Arctic Bay	-42.2	-43.6	-42.2	-34.7	-20.6	-6.7	-0.3	-1.7	-10.0	-25.6	-33.9	-41.1
Brevoort Island	-33.3	-35.6	-32.5	-25.0	-15.6	-6.7	-2.5	-1.9	-7.2	-14.7	-23.3	-31.1
Cambridge Bay A	-46.7	-46.4	-43.3	-37.5	-24.4	-10.8	1.4	-1.1	-11.9	-27.2	-37.8	-42.5
Cape Dyer A	-39.4	-38.9	-37.8	-28.6	-18.9	-6.7	-1.7	-2.2	-12.2	-20.6	-30.6	-37.8
Cape Hooper	-38.3	-36.7	-36.1	-28.3	-18.9	-7.5	-3.6	-3.6	-9.2	-19.2	-28.1	-34.2
Cape Hopes Advance	-35.6	-35.6	-31.7	-24.7	-13.1	-4.4	-1.7	0.6	-2.2	-9.4	-18.9	-30.6
Cape Parry A	-42.2	-43.3	-39.2	-32.8	-21.1	-7.8	-1.4	-2.2	-8.3	-20.8	-32.2	-38.3
Chesterfield	-46.1	-45.0	-41.9	-32.2	-22.2	-6.1	1.1	1.9	-6.7	-21.7	-35.0	-40.6
Churchill A	-40.6	-40.0	-35.6	-27.2	-16.1	-3.3	0.8	3.3	-3.9	-15.6	-30.0	-36.7
Clinton Point	-40.6	-41.7	-37.5	-31.9	-19.4	-7.5	-1.1	-1.7	-8.6	-20.6	-30.3	-36.1
Clyde	-40.6	-40.8	-39.2	-30.8	-20.8	-7.2	-1.9	-1.9	-7.8	-20.0	-30.3	-36.9
Coburg Island	-35.3	-36.7	-35.3	-27.8	-18.1	-8.9	-1.9	-0.8	-12.5	-23.3	-31.1	-36.1
Coppermine	-44.2	-45.0	-40.6	-33.3	-21.1	-7.2	1.9	0.3	-7.8	-23.3	-35.0	-40.6
Coral Harbour A	-45.6	-44.2	-40.6	-32.5	-21.7	-7.8	0.6	-0.3	-8.9	-24.4	-35.6	-41.1
Eureka	-48.9	-49.7	-49.2	-42.5	-25.3	-7.5	0.3	-3.9	-24.4	-37.2	-43.9	-48.1
Frobisher Bay A	-41.1	-41.1	-38.9	-30.0	-16.1	-4.4	1.1	0.8	-5.0	-19.2	-30.0	-38.1
Gladman Point	-48.1	-47.2	-43.9	-37.2	-25.6	-10.3	-0.3	-1.9	-11.1	-26.4	-39.7	-43.6
Hall Beach A	-46.1	-45.3	-44.7	-35.3	-24.2	-10.8	-1.1	-1.1	-9.4	-26.1	-37.8	-41.4
Inoucdjouac	-38.9	-38.1	-36.7	-27.8	-13.3	-4.2	0.3	1.7	-1.7	-10.0	-21.9	-36.1
Isachsen	-47.8	-48.9	-47.8	-39.7	-24.2	-10.6	-2.2	-7.2	-21.9	-34.2	-42.5	-46.4
Johnson Point	-48.3	-42.8	-43.3	-33.6	-21.7	-11.4	-0.6	-2.2	-16.1	-29.7	-39.4	-40.8
Komakuk Beach	-45.8	-42.8	-38.6	-31.7	-21.1	-6.4	-1.9	-1.9	-11.1	-23.9	-33.6	-41.1
Longstaff Bluff	-45.0	-42.8	-41.1	-31.7	-21.4	-7.8	-1.7	-2.8	-8.9	-24.2	-35.6	-40.0
Mackar Inlet	-48.3	-45.6	-43.1	-35.0	-22.5	-11.1	-2.2	-4.4	-12.8	-26.7	-38.3	-41.7
Mould Bay	-46.9	-47.5	-46.1	-38.1	-23.3	-10.0	-1.9	-5.6	-19.4	-31.1	-40.0	-43.9
Nottingham Island	-35.6	-36.1	-34.2	-27.2	-15.3	-4.7	-0.6	0.0	-4.2	-15.0	-23.9	-31.7
Rea Point A	-48.1	-43.3	-45.8	-38.9	-24.7	-12.2	-1.9	-5.0	-17.5	-28.3	-39.4	-42.5
Resolute A	-45.6	-45.6	-43.6	-37.5	-23.9	-11.4	-1.9	-4.4	-16.1	-28.9	-38.1	-40.8
Resolution Island	-31.7	-29.4	-26.4	-20.0	-10.6	-4.4	-1.9	-1.7	-2.2	-9.4	-16.7	-23.9
Sachs Harbour	-46.1	-44.4	-41.9	-35.6	-21.7	-8.3	-1.9	-3.9	-15.8	-26.1	-36.7	-41.7
Tuktoyaktuk	-38.9	-43.3	-38.9	-33.6	-20.0	-5.3	0.3	-0.3	-7.8	-21.9	-35.6	-41.7

Table 2d

Ten-Percentile Values of High Wind Speed (km/h)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Alert	27	27	18	24	26	27	37	32	31	34	27	32
Arctic Bay	19	19	15	19	19	23	24	24	18	21	16	16
Brevoort Island	53	56	58	48	42	35	35	37	39	42	45	50
Cambridge Bay A	39	37	35	35	34	35	34	35	39	40	37	35
Cape Dyer A	44	37	31	29	32	26	23	23	32	35	35	42
Cape Hooper	39	32	35	37	34	31	27	31	39	44	40	45
Cape Hopes Advance	47	47	40	44	42	39	35	42	53	58	60	56
Cape Parry A	37	34	35	35	34	34	31	32	34	37	35	35
Chesterfield	35	39	35	35	35	29	26	32	37	42	39	35
Churchill A	39	37	34	37	34	32	32	32	39	40	44	35
Clinton Point	53	44	44	35	34	31	32	34	34	40	44	47
Clyde	24	27	21	19	24	21	18	21	24	31	27	24
Coburg Island	32	39	37	23	35	44	37	31	35	29	31	40
Coppermine	34	26	26	24	23	23	23	24	29	34	29	26
Coral Harbour A	35	37	34	35	37	35	32	34	37	37	44	39
Eureka	24	23	21	21	24	27	29	23	23	21	21	23
Frobisher Bay A	35	35	34	35	35	32	27	27	34	35	35	35
Gladman Point	34	35	34	35	35	34	34	34	37	40	35	34
Hall Beach A	37	37	35	34	34	31	27	32	39	42	40	35
Inoucdjouac	37	35	35	37	35	32	32	32	35	37	39	37
Isachsen	44	40	34	32	35	35	31	34	34	35	37	37
Johnson Point	35	35	32	35	35	32	27	27	29	31	34	32
Komakuk Beach	42	39	39	29	35	32	29	26	29	39	39	39
Longstaff Bluff	37	34	31	31	31	27	29	27	34	32	34	32
Mackar Inlet	24	24	26	29	29	26	24	26	27	32	31	26
Mould Bay	35	34	29	27	27	31	31	31	34	34	31	32
Nottingham Island	34	35	31	34	34	29	24	32	35	37	40	37
Rea Point A	39	42	37	34	34	34	34	35	39	37	35	39
Resolute A	47	45	42	40	40	37	37	40	40	45	42	42
Resolution Island	61	56	47	47	39	40	37	42	42	55	53	61
Sachs Harbour	32	29	29	34	34	29	31	34	35	37	34	32
Tuktoyaktuk	34	31	31	29	27	24	29	31	32	32	32	32

Table 2e

Three-Percentile Values of High Wind Speed (km/h)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Alert	55	53	47	52	47	42	52	47	47	53	52	53
Arctic Bay	31	31	24	31	27	32	35	35	26	31	26	26
Brevoort Island	71	79	79	64	55	48	48	48	53	53	60	64
Cambridge Bay A	53	48	45	45	45	45	44	45	52	53	47	45
Cape Dyer A	63	55	53	47	45	39	32	35	44	50	50	58
Cape Hooper	61	56	58	61	50	47	44	48	58	61	60	68
Cape Hopes Advance	68	64	55	60	56	50	48	55	69	74	76	74
Cape Parry A	48	45	44	45	44	42	39	39	42	47	44	45
Chesterfield	47	50	44	47	44	40	35	44	50	55	48	45
Churchill A	50	48	47	47	45	42	40	44	52	53	55	47
Clinton Point	72	63	61	53	45	40	44	45	45	53	58	63
Clyde	40	45	37	35	37	34	27	32	37	42	44	42
Coburg Island	56	56	50	40	50	60	45	45	47	47	40	52
Coppermine	45	39	37	35	32	29	32	35	40	44	40	39
Coral Harbour A	53	55	48	48	50	45	44	45	48	50	58	55
Eureka	39	35	32	32	35	39	39	32	34	32	32	34
Frobisher Bay A	48	50	47	47	47	40	39	40	45	47	47	48
Gladman Point	45	47	45	44	44	42	42	42	47	50	45	47
Hall Beach A	48	48	47	42	44	40	39	44	50	55	52	45
Inoucdjouac	48	47	47	47	45	42	40	40	45	48	52	53
Isachsen	64	60	50	48	48	47	44	44	45	48	50	56
Johnson Point	48	44	40	42	42	39	39	37	40	42	44	42
Komakuk Beach	55	50	48	40	42	40	39	35	39	50	50	50
Longstaff Bluff	50	44	44	42	40	39	40	39	44	44	44	44
Mackar Inlet	39	37	42	44	42	35	37	37	42	45	47	42
Mould Bay	50	47	44	40	39	42	42	40	42	45	44	47
Nottingham Island	47	48	45	45	44	42	35	44	48	50	56	52
Rea Point A	48	53	47	42	42	40	40	44	52	48	45	50
Resolute A	61	60	60	55	53	48	50	56	52	58	58	56
Resolution Island	85	79	63	63	60	56	48	55	58	71	64	82
Sachs Harbour	47	40	42	44	40	39	40	42	45	47	44	42
Tuktoyaktuk	44	40	40	39	37	35	40	40	40	40	42	44

Table 2f

One-Percentile Values of High Wind Speed (km/h)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Alert	72	69	63	69	60	52	60	56	58	63	68	68
Arctic Bay	40	40	31	39	35	42	44	42	32	39	32	32
Brevoort Island	82	90	95	77	64	56	60	56	60	61	66	74
Cambridge Bay A	63	58	53	53	53	53	52	53	61	63	56	55
Cape Dyer A	77	66	69	60	56	47	42	45	52	63	61	69
Cape Hooper	76	77	72	77	64	60	55	60	74	74	76	84
Cape Hopes Advance	81	76	63	71	64	61	61	64	77	84	85	85
Cape Parry A	56	53	48	55	50	48	45	45	48	56	52	52
Chesterfield	56	60	53	55	50	47	44	52	61	63	56	52
Churchill A	60	58	56	55	53	48	47	52	61	61	63	55
Clinton Point	84	76	71	64	53	48	48	53	53	60	68	74
Clyde	52	60	48	47	44	45	35	40	45	53	55	55
Coburg Island	64	71	56	50	60	69	52	60	52	56	47	60
Coppermine	53	47	45	44	42	37	40	45	47	52	47	45
Coral Harbour A	64	69	56	58	58	53	52	53	60	60	69	66
Eureka	48	47	44	42	44	44	45	42	42	42	44	40
Frobisher Bay A	61	61	58	56	56	48	47	48	53	56	56	58
Gladman Point	55	56	53	52	50	48	47	48	55	58	52	55
Hall Beach A	56	56	55	50	53	48	45	52	58	64	60	53
Inoucdjouac	58	56	53	56	53	48	47	47	55	56	60	63
Isachsen	81	74	66	58	60	55	52	50	53	58	60	69
Johnson Point	61	50	47	48	45	44	45	44	47	47	50	47
Komakuk Beach	63	58	55	48	47	45	44	42	44	56	58	56
Longstaff Bluff	60	52	50	52	48	47	45	44	50	52	50	52
Mackar Inlet	50	45	53	53	50	42	47	44	55	55	56	58
Mould Bay	63	56	52	50	47	47	48	48	50	53	50	58
Nottingham Island	56	56	53	55	52	52	42	53	61	61	66	63
Rea Point A	56	61	56	52	47	48	45	52	60	56	53	58
Resolute A	72	69	68	64	63	56	60	66	61	66	69	69
Resolution Island	103	100	74	76	72	66	56	63	72	85	74	101
Sachs Harbour	55	47	50	48	48	45	47	48	53	55	55	52
Tuktoyaktuk	52	47	45	44	45	42	45	47	45	45	48	52

Table 3

Representative Temperatures (°C) for Each of the 13 Zones

PERCENTILE LEVELS												
Zone	10	3	1	10	3	1	10	3	1	10	3	1
	January			February			March			April		
A	-46	-48	-49	-46	-49	-50	-46	-47	-49	-38	-41	-43
B	-42	-46	-48	-44	-47	-48	-41	-44	-46	-32	-36	-38
C	-42	-44	-46	-42	-46	-47	-39	-42	-44	-32	-34	-37
D	-43	-46	-48	-43	-45	-47	-41	-43	-46	-33	-36	-38
E	-44	-47	-49	-43	-47	-48	-41	-44	-46	-32	-35	-38
F	-42	-44	-47	-42	-44	-46	-41	-43	-44	-33	-35	-38
G	-43	-46	-48	-43	-46	-47	-40	-43	-45	-30	-34	-36
H	-39	-42	-44	-39	-42	-44	-39	-42	-44	-32	-35	-37
I	-39	-41	-43	-39	-42	-44	-38	-41	-42	-31	-33	-36
J	-33	-36	-38	-33	-36	-39	-30	-34	-36	-25	-27	-28
K	-36	-38	-39	-36	-38	-41	-33	-36	-38	-26	-28	-30
L	-36	-37	-39	-35	-38	-40	-32	-36	-38	-22	-27	-29
M	-27	-31	-33	-27	-30	-33	-26	-30	-32	-19	-23	-24

PERCENTILE LEVELS												
Zone	10	3	1	10	3	1	10	3	1	10	3	1
	July			August			September			October		
A	- 2	- 3	- 4	- 4	- 7	- 8	-18	-22	-24	-32	-36	-38
B	- 2	- 3	- 4	- 2	- 5	- 6	-12	-18	-19	-24	-26	-29
C	- 1	- 2	- 3	- 2	- 3	- 5	- 8	-14	-16	-22	-24	-27
D	- 1	- 2	- 2	- 3	- 5	- 6	-14	-18	-19	-26	-29	-32
E	0	- 2	- 2	- 2	- 3	- 4	- 8	-11	-14	-22	-26	-28
F	- 1	- 2	- 2	- 3	- 5	- 6	-13	-17	-19	-24	-29	-31
G	0	- 2	- 2	0	- 2	- 3	- 7	- 9	-11	-21	-25	-27
H	- 1	- 2	- 2	- 3	- 6	- 7	-17	-19	-22	-27	-29	-31
I	- 2	- 3	- 4	- 3	- 4	- 4	-12	-15	-18	-24	-27	-30
J	0	- 2	- 2	- 2	- 2	- 3	- 7	- 9	-13	-19	-22	-23
K	- 1	- 2	- 3	- 2	- 3	- 4	- 6	- 9	-12	-16	-19	-20
L	0	- 2	- 2	1	0	- 1	- 3	- 4	- 5	-10	-14	-17
M	0	- 2	- 2	- 2	- 2	- 3	- 4	- 6	- 8	- 8	-11	-13

PERCENTILE LEVELS												
Zone	10	3	1	10	3	1	10	3	1	10	3	1
	November			December								
A	-41	-43	-44	-44	-47	-48						
B	-33	-38	-41	-40	-43	-44						
C	-32	-35	-38	-38	-41	-43						
D	-36	-38	-41	-39	-42	-44						
E	-34	-38	-41	-39	-42	-44						
F	-34	-37	-38	-38	-41	-43						
G	-32	-35	-38	-39	-42	-43						
H	-34	-36	-37	-37	-39	-40						
I	-33	-35	-36	-37	-39	-41						
J	-26	-29	-30	-32	-34	-36						
K	-25	-28	-30	-32	-36	-37						
L	-23	-24	-27	-30	-34	-36						
M	-16	-22	-24	-23	-29	-31						

Table 4

Three-Percentile Values of High Cooling Index (°C - km/h)

HIGH COOLING INDEX			
Zone	October	January	April
A	950	2,100	1,200
B	850	1,500	950
C	800	1,600	1,000
D	950	1,800	1,200
E	825	1,650	1,075
F	925	1,800	1,175
G	800	1,675	1,025
H	700	1,400	900
I	800	1,500	950
J	500	1,400	875
K	500	1,500	900
L	500	1,500	950
M	325	1,500	800

Table 5

Observing Stations Used in the Duration Analysis for Each Zone

Zone	Stations Used
A	Alert, Eureka, Isachsen, Mould Bay, Rea Point A
B	Sachs Harbour
C	Cape Parry A, Clinton Point, Coppermine, Komakuk Beach, Tuktoyaktuk
D	Rea Point A, Resolute A
E	Cambridge Bay A, Gladman Point, Mackar Inlet
F	Resolute A
G	Chesterfield, Churchill A, Coral Harbour A, Hall Beach A
H	Alert
I	Arctic Bay, Cape Dyer A, Clyde, Coburg Island
J	Coburg Island
K	Cape Hopes Advance, Frobisher Bay A, Resolution Island
L	Inoucdjouac, Nottingham Island
M	Resolution Island

Table 6

Surface Air Temperature and Wind Speed Criteria Used in the Duration Analysis

Condition Number	Temperature and Wind Criteria
1	Temperature < 0°C
2	Temperature < −10°C
3	Temperature < −20°C
4	Temperature < −30°C
5	Temperature < −40°C
6	Temperature < −50°C
7	Temperature < −20°C and Wind Speed > 25 km/h
8	Temperature < −20°C and Wind Speed > 50 km/h
9	Temperature < −20°C and Wind Speed > 75 km/h
10	Temperature < −30°C and Wind Speed > 25 km/h
11	Temperature < −30°C and Wind Speed > 50 km/h
12	Temperature < −30°C and Wind Speed > 75 km/h
13	Temperature < −40°C and Wind Speed > 25 km/h
14	Temperature < −40°C and Wind Speed > 50 km/h
15	Temperature < −40°C and Wind Speed > 75 km/h

Note: Conditions 7 to 15 are equivalent to the following cooling rates. Based on Siple and Passel's formula (3).

Condition Number	Cooling Rate
7	1580 kcal/m² − hr
8	1790 kcal/m² − hr
9	1870 kcal/m² − hr
10	1880 kcal/m² − hr
11	2130 kcal/m² − hr
12	2220 kcal/m² − hr
13	2180 kcal/m² − hr
14	2470 kcal/m² − hr
15	2570 kcal/m² − hr

Table 7
Maximum Monthly Duration (hours) of Temperature < 0°C for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	*	*	*	*	*	285	69	*	*	*	*	*
B	*	*	*	*	519	237	39	333	*	*	*	*
C	*	*	*	*	719	192	30	121	*	*	*	*
D	*	*	*	*	*	232	19	*	*	*	*	*
E	*	*	*	*	*	306	72	636	*	*	*	*
F	*	*	*	*	*	232	19	*	*	*	*	*
G	*	*	*	*	*	249	11	36	*	*	*	*
H	*	*	*	*	*	216	69	*	*	*	*	*
I	*	*	*	*	*	210	25	66	*	*	*	*
J	*	*	*	*	*	86	15	5	*	*	*	*
K	*	*	*	*	378	135	15	15	*	*	*	*
L	*	*	*	*	405	87	15	9	222	*	*	*
M	*	*	*	*	252	135	15	15	120	708	*	*

* *Implies that the maximum duration lasted throughout the month in question.*

Table 8
Maximum Monthly Duration (hours) of Temperature < −10°C for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	*	*	*	*	474	30	0	3	*	*	*	*
B	*	*	*	603	168	7	0	0	182	*	*	*
C	*	*	*	632	281	8	6	0	16	*	*	*
D	*	*	*	*	474	48	0	0	*	*	*	*
E	*	*	*	*	405	36	1	0	186	*	*	*
F	*	*	*	*	474	31	0	0	590	*	*	*
G	*	*	*	*	350	15	0	0	53	*	*	*
H	*	*	*	*	471	15	0	3	*	*	*	*
I	*	*	*	714	306	9	0	0	78	*	*	*
J	*	*	*	366	60	0	0	0	78	*	*	*
K	*	*	*	359	75	0	0	0	5	233	*	*
L	*	*	*	306	60	0	0	0	0	291	*	*
M	*	636	*	216	24	0	0	0	0	3	108	*

* *Implies that the maximum duration lasted throughout the month in question.*

Table 9
Maximum Monthly Duration (hours) of Temperature < -20°C for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	*	*	*	705	87	0	0	0	99	*	*	*
B	*	*	*	282	21	0	0	0	4	265	*	*
C	*	*	*	283	30	0	0	0	0	259	*	*
D	*	*	*	476	63	0	0	0	0	287	*	*
E	*	*	*	429	78	0	0	0	0	198	*	*
F	*	*	*	476	63	0	0	0	0	287	*	*
G	*	*	*	327	20	1	0	0	0	226	*	*
H	*	*	*	603	87	0	0	0	39	*	*	*
I	*	*	*	354	15	0	0	0	0	156	*	*
J	*	372	240	90	6	0	0	0	0	78	138	*
K	*	*	594	94	6	0	0	0	0	42	366	596
L	*	*	390	105	9	0	0	0	0	0	549	510
M	603	297	132	18	0	0	0	0	0	0	0	156

* *Implies that the maximum duration lasted throughout the month in question.*

Table 10
Maximum Monthly Duration (hours) of Temperature < -30°C for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	672	*	*	237	3	0	0	0	0	294	*	*
B	426	489	282	46	0	0	0	0	0	18	82	471
C	420	390	323	48	0	0	0	0	0	0	100	379
D	608	*	396	131	0	0	0	0	0	26	324	380
E	*	*	351	132	6	0	0	0	0	40	222	488
F	608	*	347	131	0	0	0	0	0	26	236	280
G	617	630	285	46	1	0	0	0	0	13	456	384
H	378	558	453	180	0	0	0	0	0	81	363	504
I	648	546	486	24	0	0	0	0	0	0	180	360
J	36	54	54	0	0	0	0	0	0	0	12	66
K	298	355	116	11	0	0	0	0	0	0	23	212
L	144	123	42	9	0	0	0	0	0	0	0	84
M	36	3	0	0	0	0	0	0	0	0	0	0

* *Implies that the maximum duration lasted throughout the month in question.*

Table 11
Maximum Monthly Duration (hours) of Temperature < -40°C for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	258	408	261	45	0	0	0	0	0	6	99	309
B	98	132	34	0	0	0	0	0	0	0	11	48
C	131	154	66	6	0	0	0	0	0	0	0	84
D	120	135	87	5	0	0	0	0	0	0	24	48
E	207	144	132	12	0	0	0	0	0	0	24	108
F	119	135	75	5	0	0	0	0	0	0	10	48
G	258	115	85	4	0	0	0	0	0	0	6	174
H	69	114	111	21	0	0	0	0	0	0	6	45
I	60	114	18	0	0	0	0	0	0	0	0	42
J	0	0	0	0	0	0	0	0	0	0	0	0
K	38	32	9	0	0	0	0	0	0	0	0	7
L	15	9	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0

Table 12
Maximum Monthly Duration (hours) of Temperature < -50°C for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	30	45	15	0	0	0	0	0	0	0	0	18
B	26	11	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0
D	3	0	3	0	0	0	0	0	0	0	0	0
E	9	6	0	0	0	0	0	0	0	0	0	0
F	3	0	3	0	0	0	0	0	0	0	0	0
G	6	0	0	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0

Table 13
Maximum Monthly Duration (hours) of Temperature < -20°C with Wind Speed > 25km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	108	120	94	87	15	0	0	0	15	62	92	123
B	78	69	60	51	12	0	0	0	0	42	66	84
C	108	162	130	62	8	0	0	0	0	102	102	120
D	114	96	97	68	12	0	0	0	0	62	92	96
E	107	138	107	60	18	0	0	0	0	36	123	108
F	114	77	97	63	12	0	0	0	0	41	75	96
G	222	232	122	102	17	0	0	0	0	50	99	99
H	57	81	78	27	3	0	0	0	12	21	66	87
I	48	51	66	30	0	0	0	0	0	12	27	60
J	48	30	66	30	0	0	0	0	0	0	12	60
K	120	151	82	60	1	0	0	0	0	20	66	68
L	81	84	60	39	3	0	0	0	0	0	24	57
M	111	138	51	9	0	0	0	0	0	0	0	45

Table 14
Maximum Monthly Duration (hours) of Temperature < -20°C with Wind Speed > 50 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	66	78	60	30	6	0	0	0	3	18	30	78
B	29	18	11	27	0	0	0	0	0	0	42	18
C	60	114	72	36	0	0	0	0	0	42	45	48
D	70	37	40	12	9	0	0	0	0	14	29	24
E	50	30	36	30	0	0	0	0	0	12	30	30
F	70	36	40	10	9	0	0	0	0	14	29	24
G	43	41	48	27	2	0	0	0	0	4	35	46
H	36	54	48	21	0	0	0	0	3	18	21	39
I	36	30	28	13	0	0	0	0	0	0	9	25
J	36	18	12	6	0	0	0	0	0	0	0	24
K	48	45	39	21	0	0	0	0	0	0	13	31
L	42	30	36	18	0	0	0	0	0	0	3	45
M	48	45	15	0	0	0	0	0	0	0	0	24

Table 15
Maximum Monthly Duration (hours) of Temperature < -20°C with Wind Speed > 75 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	39	39	24	6	0	0	0	0	0	3	9	27
B	6	3	0	3	0	0	0	0	0	0	3	3
C	30	18	24	6	0	0	0	0	0	1	9	30
D	27	15	4	3	0	0	0	0	0	0	4	8
E	10	6	6	1	0	0	0	0	0	0	0	18
F	27	15	4	3	0	0	0	0	0	0	4	8
G	11	13	23	0	0	0	0	0	0	0	8	11
H	24	33	24	3	0	0	0	0	0	3	9	6
I	12	12	13	5	0	0	0	0	0	0	1	6
J	0	12	0	0	0	0	0	0	0	0	0	0
K	33	12	24	12	0	0	0	0	0	0	0	15
L	3	3	3	3	0	0	0	0	0	0	0	3
M	33	12	3	0	0	0	0	0	0	0	0	6

Table 16
Maximum Monthly Duration (hours) of Temperature < -30°C with Wind Speed > 25 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	108	79	63	48	0	0	0	0	0	15	36	123
B	61	33	33	33	0	0	0	0	0	0	15	30
C	78	102	72	48	0	0	0	0	0	0	24	56
D	78	79	60	31	0	0	0	0	0	15	30	56
E	75	132	54	30	0	0	0	0	0	6	61	72
F	78	77	52	31	0	0	0	0	0	15	30	56
G	100	125	82	35	0	0	0	0	0	0	48	78
H	51	36	24	12	0	0	0	0	0	0	15	18
I	18	30	23	6	0	0	0	0	0	0	12	18
J	0	12	0	0	0	0	0	0	0	0	0	18
K	42	41	37	7	0	0	0	0	0	0	17	40
L	30	30	18	3	0	0	0	0	0	0	0	6
M	24	3	0	0	0	0	0	0	0	0	0	0

Table 17
Maximum Monthly Duration (hours) of Temperature < -30°C with Wind Speed > 50 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	66	48	42	15	0	0	0	0	0	0	15	78
B	24	9	9	0	0	0	0	0	0	0	3	6
C	48	66	30	6	0	0	0	0	0	0	0	30
D	25	37	23	3	0	0	0	0	0	1	13	15
E	50	30	27	6	0	0	0	0	0	0	12	14
F	25	19	23	3	0	0	0	0	0	1	13	15
G	37	26	48	5	0	0	0	0	0	0	26	13
H	21	15	18	0	0	0	0	0	0	0	3	9
I	9	9	9	0	0	0	0	0	0	0	0	18
J	0	6	0	0	0	0	0	0	0	0	0	18
K	16	22	13	3	0	0	0	0	0	0	1	10
L	27	9	3	3	0	0	0	0	0	0	0	0
M	9	3	0	0	0	0	0	0	0	0	0	0

Table 18
Maximum Monthly Duration (hours) of Temperature < -30°C with Wind Speed > 75 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	36	12	18	6	0	0	0	0	0	0	6	18
B	0	0	0	0	0	0	0	0	0	0	0	0
C	18	12	12	0	0	0	0	0	0	0	0	24
D	6	3	1	0	0	0	0	0	0	0	0	1
E	10	6	3	0	0	0	0	0	0	0	0	4
F	6	3	1	0	0	0	0	0	0	0	0	1
G	7	5	0	0	0	0	0	0	0	0	1	0
H	0	6	18	0	0	0	0	0	0	0	0	0
I	0	5	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	9	4	4	0	0	0	0	0	0	0	0	1
L	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0

Table 19

Maximum Monthly Duration (hours) of Temperature < -40°C with Wind Speed > 25 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	27	21	24	3	0	0	0	0	0	0	1	9
B	24	15	5	0	0	0	0	0	0	0	0	9
C	28	24	12	0	0	0	0	0	0	0	0	9
D	45	17	24	1	0	0	0	0	0	0	2	8
E	48	38	24	1	0	0	0	0	0	0	2	12
F	45	17	8	0	0	0	0	0	0	0	2	6
G	39	67	26	0	0	0	0	0	0	0	1	30
H	9	0	0	0	0	0	0	0	0	0	0	0
I	12	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	1	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0

Table 20

Maximum Monthly Duration (hours) of Temperature < -40°C with Wind Speed > 50 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	6	5	3	0	0	0	0	0	0	0	0	9
B	0	0	0	0	0	0	0	0	0	0	0	0
C	4	1	0	0	0	0	0	0	0	0	0	0
D	3	5	1	0	0	0	0	0	0	0	0	0
E	7	7	0	0	0	0	0	0	0	0	0	1
F	3	3	0	0	0	0	0	0	0	0	0	0
G	7	6	1	0	0	0	0	0	0	0	0	0
H	3	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0

Table 21
Maximum Monthly Duration (hours) of Temperature < -40°C with Wind Speed > 75 km/h for Each of the Zones in Figure 5

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	0
E	1	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0

Table 22a

Expected Extreme Low Temperatures (°C) for Each Zone with 90-Percent Confidence Intervals
Annual Values

Zone	Representative Station	Return Period (yr)				
		2	5	10	20	50
A	Eureka	−50 ± 0.5	−52 ± 0.9	−53 ± 1.3	−54 ± 1.6	−56 ± 2.1
B	Sachs Harbour	−45 ± 0.9	−48 ± 1.7	−50 ± 2.3	−52 ± 3.0	−54 ± 3.9
C	Coppermine	−44 ± 0.5	−47 ± 0.9	−48 ± 1.2	−50 ± 1.6	−51 ± 2.0
D	Rea Point A	−48 ± 1.8	−51 ± 3.5	−52 ± 5.0	−54 ± 6.5	
E	Cambridge Bay A	−47 ± 0.4	−48 ± 0.8	−49 ± 1.1	−50 ± 1.4	−51 ± 1.8
F	Resolute A	−46 ± 0.7	−48 ± 1.3	−50 ± 1.8	−52 ± 2.2	−54 ± 2.9
G	Hall Beach A	−46 ± 0.6	−48 ± 1.1	−49 ± 1.5	−50 ± 1.9	−52 ± 2.5
H	Alert	−46 ± 0.5	−48 ± 0.8	−49 ± 1.2	−50 ± 1.5	−51 ± 1.9
I	Arctic Bay	−44 ± 0.6	−47 ± 1.2	−48 ± 1.6	−49 ± 2.1	−51 ± 2.6
J	Coburg Island *					
K	Frobisher Bay A	−42 ± 0.6	−44 ± 1.1	−46 ± 1.5	−47 ± 1.9	−49 ± 2.5
L	Nottingham Island	−38 ± 0.4	−39 ± 0.8	−40 ± 1.1	−41 ± 1.3	−43 ± 1.7
M	Resolution Island	−31 ± 0.7	−34 ± 1.2	−35 ± 1.7	−37 ± 2.2	−38 ± 2.8

* *Period of record insufficient to calculate expected extremes.*

Note: *Expected extremes have been calculated only up to return periods approximately twice the length of the period of record at each station.*

Table 22b

Expected Extreme Low Temperatures (°C) for Each Zone with 90-Percent Confidence Intervals Seasonal (July to October) Values

Zone	Representative Station	Return Period (yr)				
		2	5	10	20	50
A	Eureka	−36 ± 0.7	−38 ± 1.3	−40 ± 1.8	−42 ± 2.3	−44 ± 2.9
B	Sachs Harbour	−26 ± 1.1	−29 ± 2.0	−32 ± 2.8	−33 ± 3.6	−36 ± 4.6
C	Coppermine	−21 ± 1.1	−25 ± 2.0	−28 ± 2.7	−31 ± 3.5	−35 ± 4.4
D	Rea Point A	−29 ± 1.0	−31 ± 2.1	−32 ± 3.0	−33 ± 3.8	
E	Cambridge Bay A	−26 ± 0.8	−28 ± 1.5	−31 ± 2.1	−33 ± 2.7	−35 ± 3.4
F	Resolute A	−28 ± 0.7	−31 ± 1.4	−33 ± 1.9	−34 ± 2.4	−37 ± 3.1
G	Hall Beach A	−25 ± 1.2	−28 ± 2.2	−31 ± 3.1	−33 ± 4.0	−37 ± 5.1
H	Alert	−31 ± 0.8	−34 ± 1.5	−36 ± 2.1	−38 ± 2.6	−41 ± 3.4
I	Arctic Bay	−23 ± 1.1	−27 ± 2.0	−29 ± 2.8	−31 ± 3.5	−33 ± 4.6
J	Coburg Island *					
K	Frobisher Bay A	−17 ± 1.3	−21 ± 2.3	−24 ± 3.2	−27 ± 4.1	−30 ± 5.2
L	Nottingham Island	−12 ± 0.8	−14 ± 1.4	−17 ± 1.9	−18 ± 2.4	−21 ± 3.1
M	Resolution Island	− 8 ± 0.9	−11 ± 1.6	−13 ± 2.2	−14 ± 2.8	−17 ± 3.6

* *Period of record insufficient to calculate expected extremes.*

Note: *Expected extremes have been calculated only up to return periods approximately twice the length of the period of record at each station.*

REFERENCES

1. Government of Canada (1972). **Arctic Waters Pollution Prevention Act and Shipping Regulations**. SOR/72-426 (as amended).

2. Lloyd's Register of Shipping. (1978). Extract on "Provisional Steel Grades Distribution for LNG Carriers to Operate in Canadian Arctic at a Design Temperature of Not Less than -43°C". London, England.

3. Siple, P.A. and C.F. Passel. (1945). "Measurements of dry atmospheric cooling in sub-freezing temperatures". **Proc. Amer. Phil. Soc. 89**, pp. 177-179.

4. Kendall, G.R. (1959). "Statistical analysis of extreme values". NRCC, First Canad. Hydrol. Conf., Symp. on Spillway Design Floods, Ottawa, Nov. 4-5, pp. 54-78.

APPENDIX

Air Temperature Charts

The working charts of 3- and 1-percentile low air temperature used in this study and referred to in section 3.1 are reproduced here for reference purposes. It should be noted that the analyses are done in °F, but information derived from them and used in the main study was converted to °C.

Figures A-1 to A-12	Monthly Air Temperature (°F) not exceeded for 1% of the time (January to December)
Figures A-13 to A-24	Monthly Air Temperature (°F) not exceeded for 3% of the time (January to December)

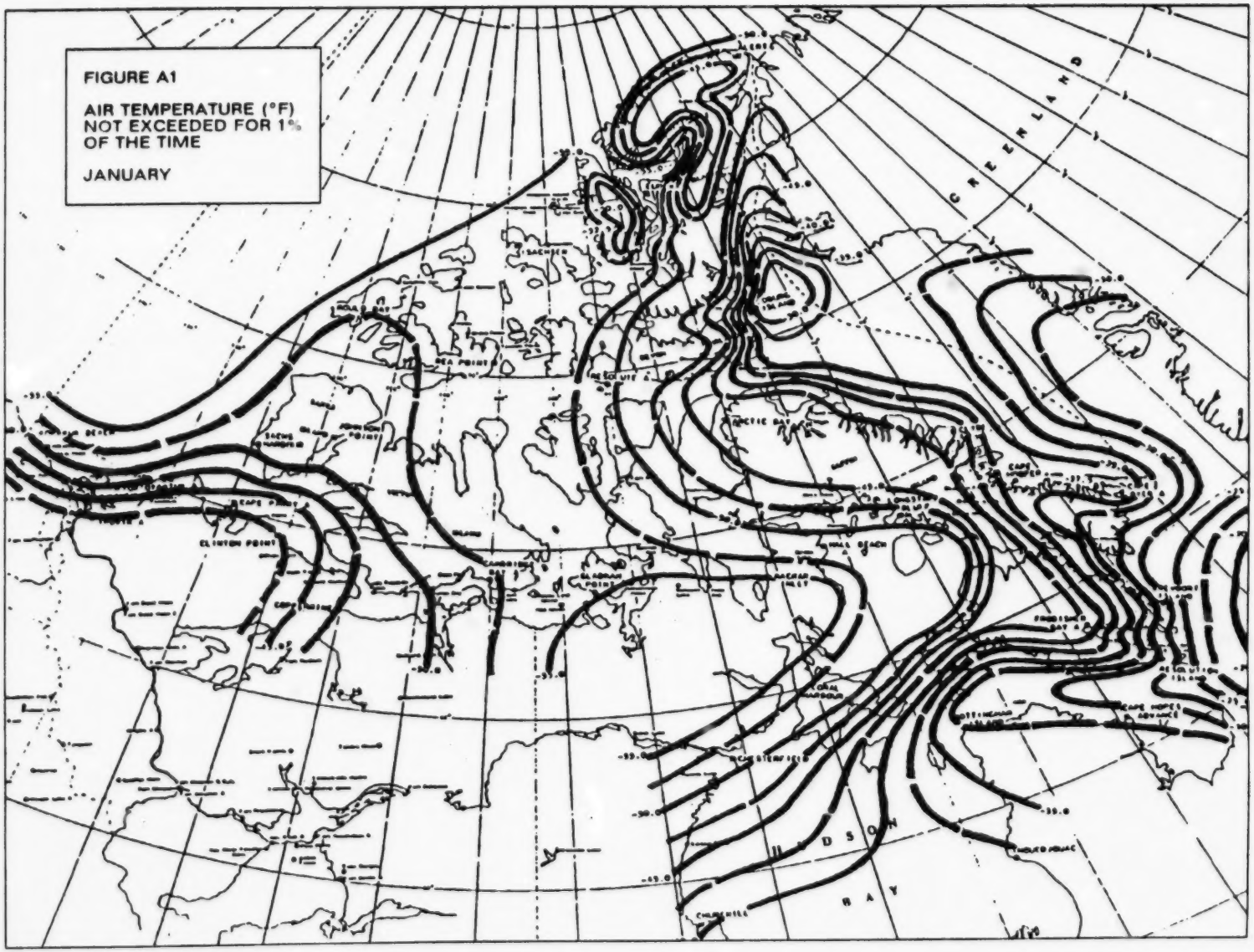


FIGURE A1
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
JANUARY
GREENLAND
HUDSON BAY

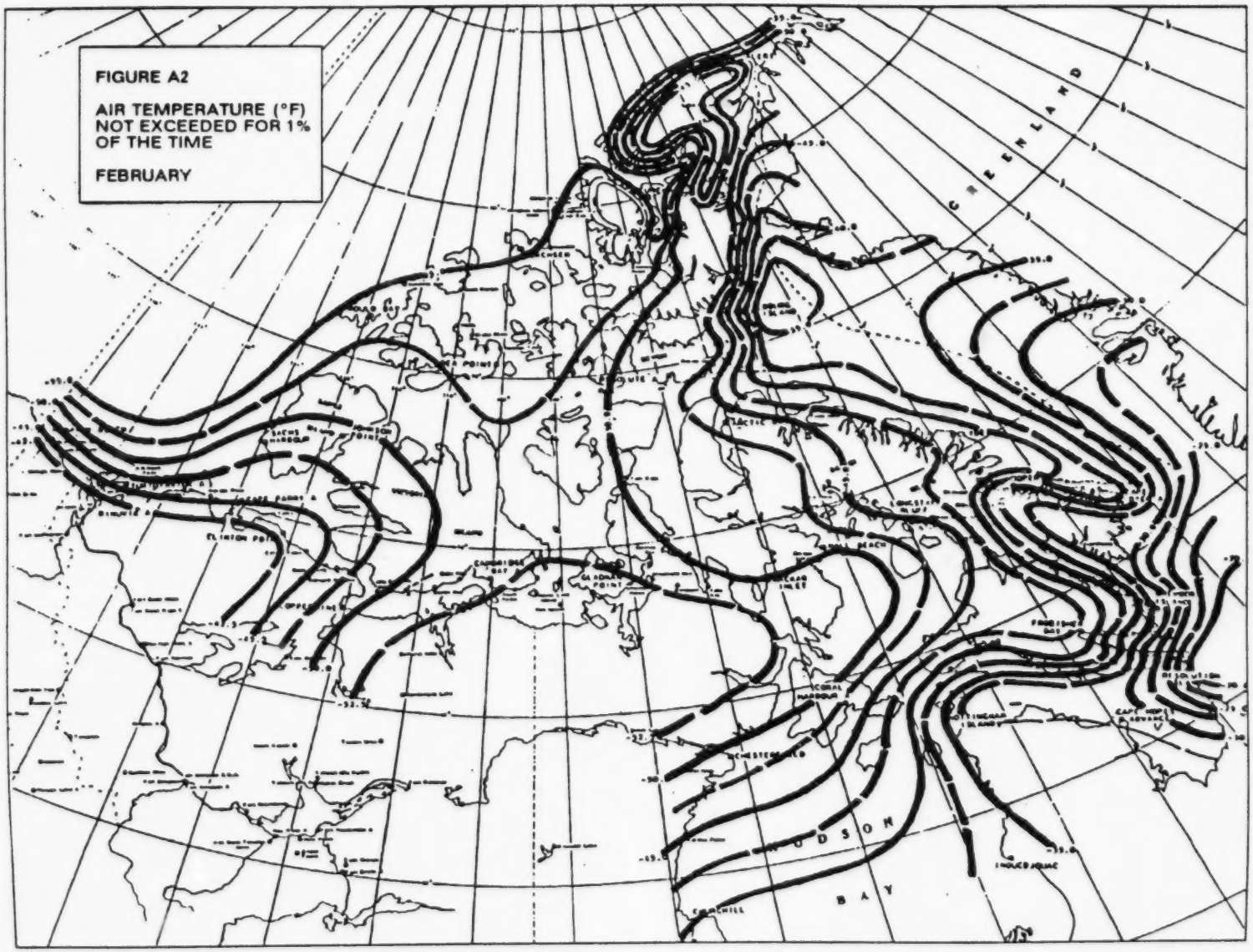


FIGURE A2
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
FEBRUARY
G R E E N L A N D
H U D S O N
B A Y

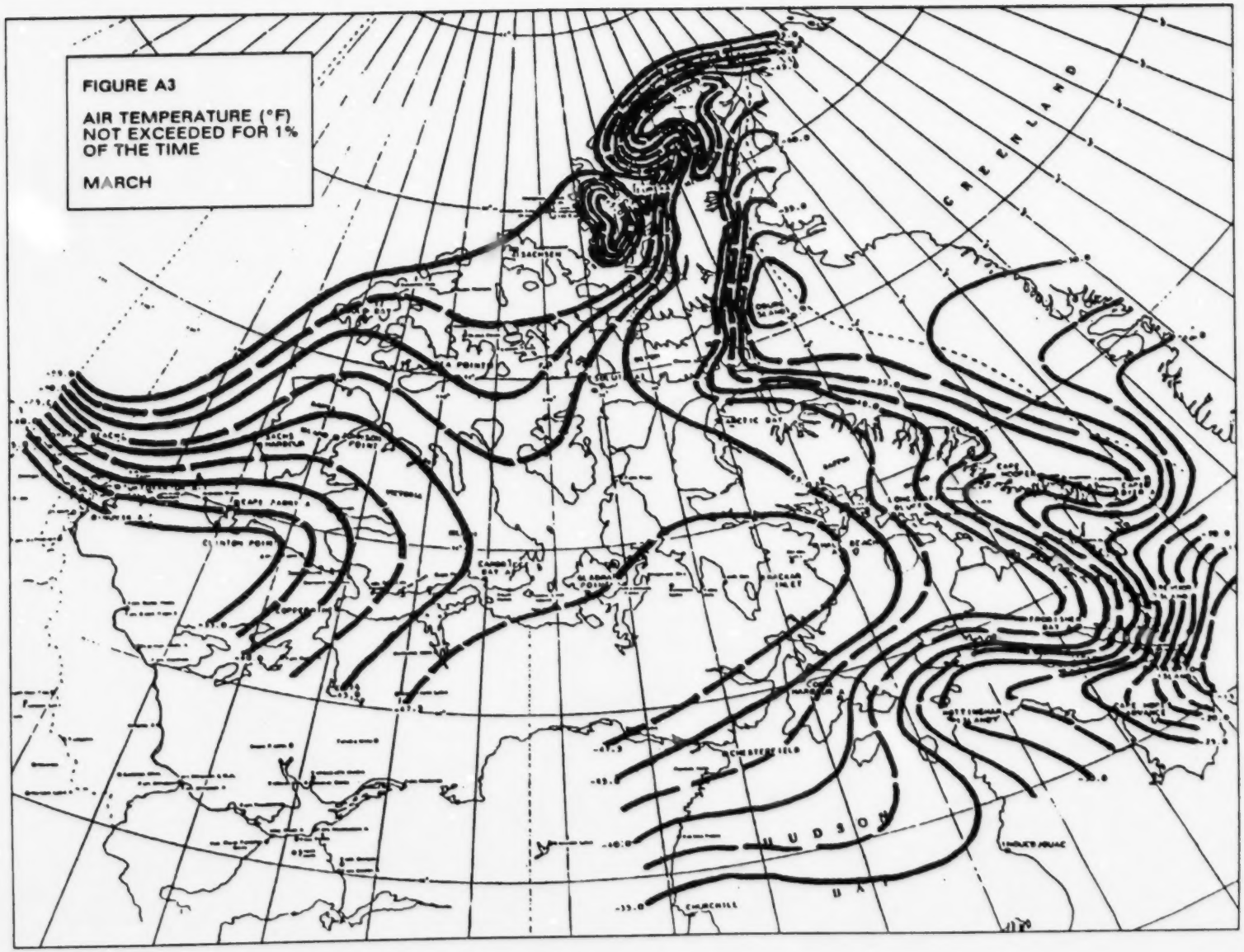


FIGURE A3
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
MARCH
GREENLAND
HUDSON

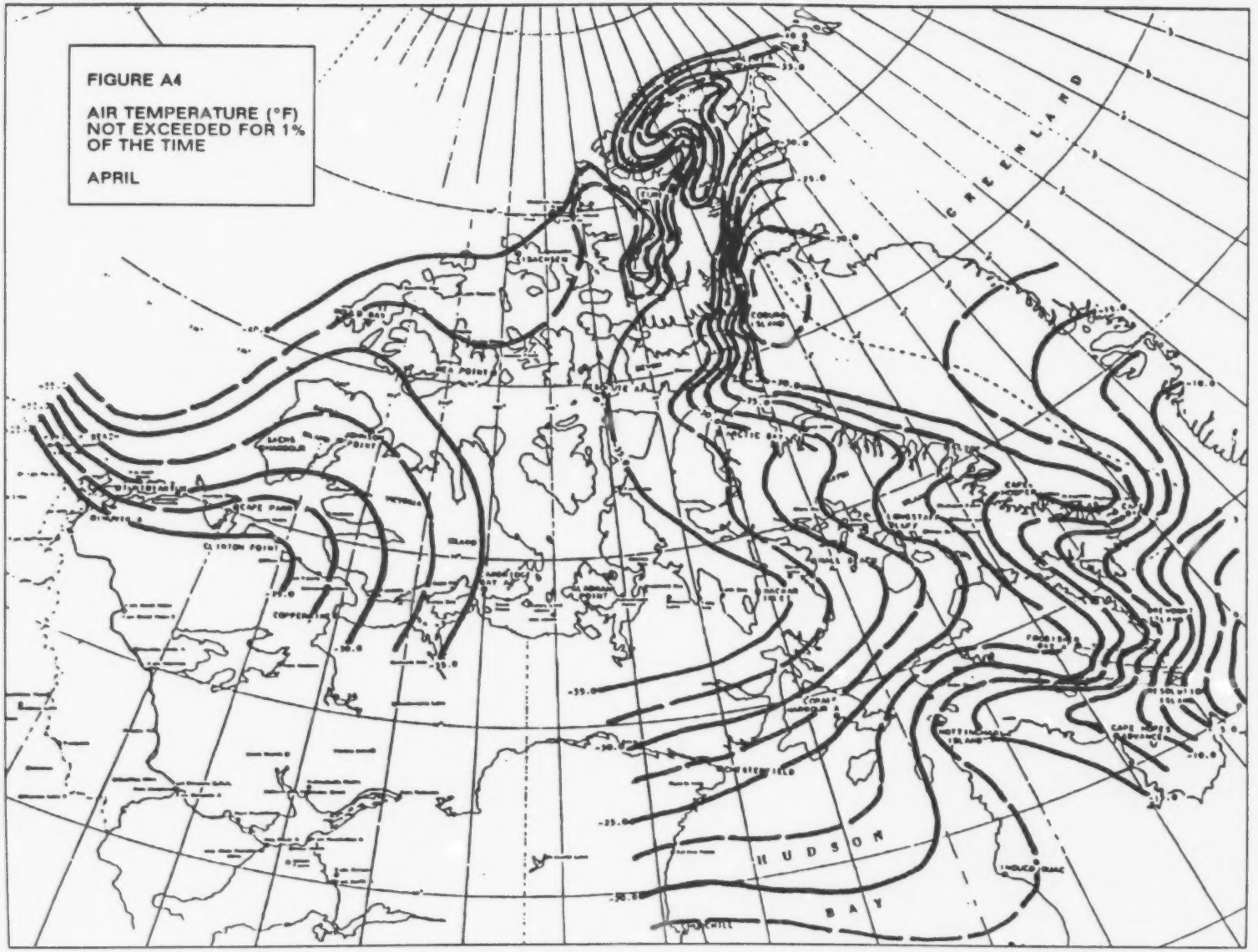


FIGURE A4
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
APRIL
GREENLAND
HUDSON
BAY

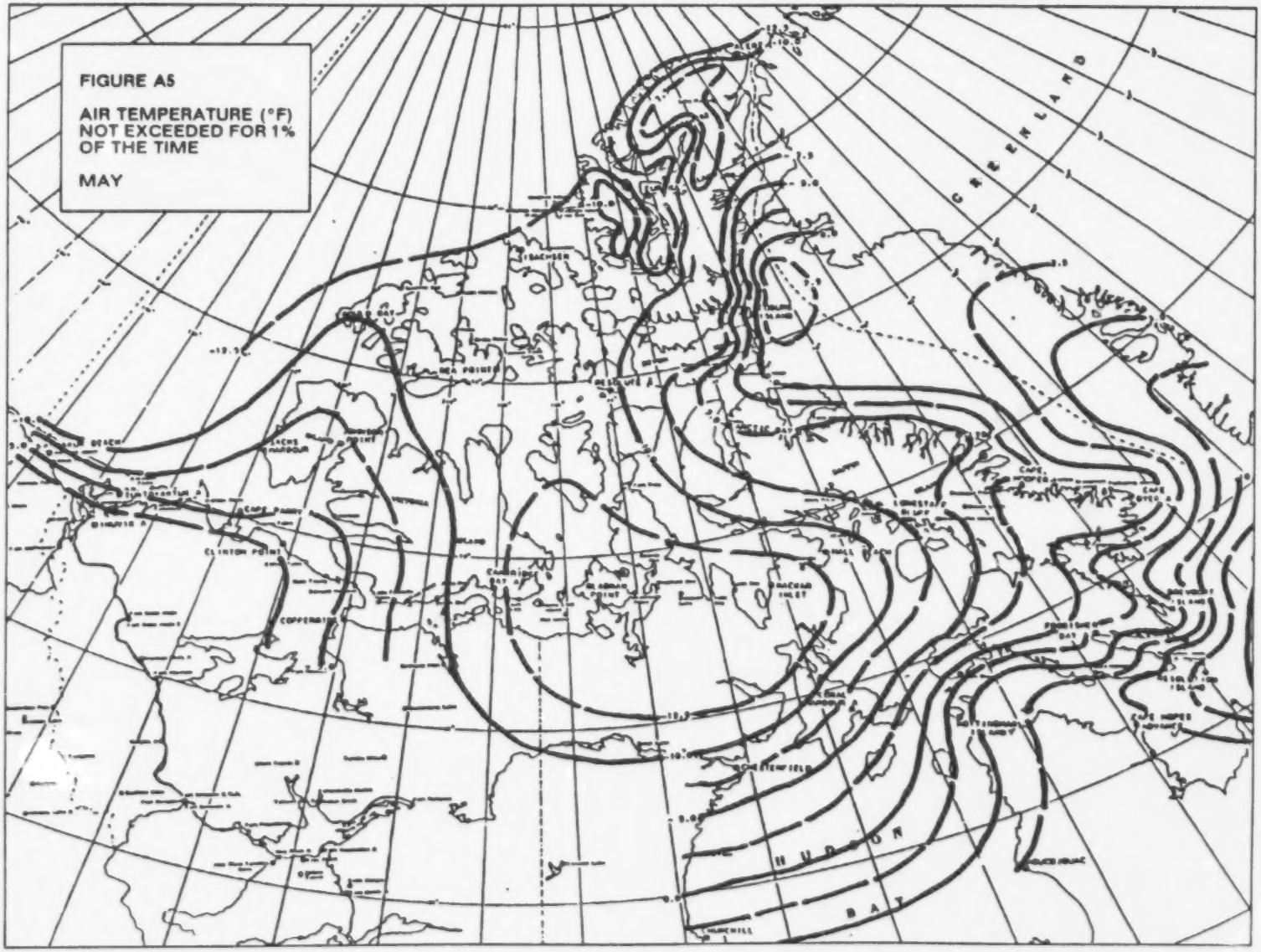


FIGURE A5
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
MAY
GREENLAND
HUDSON BAY

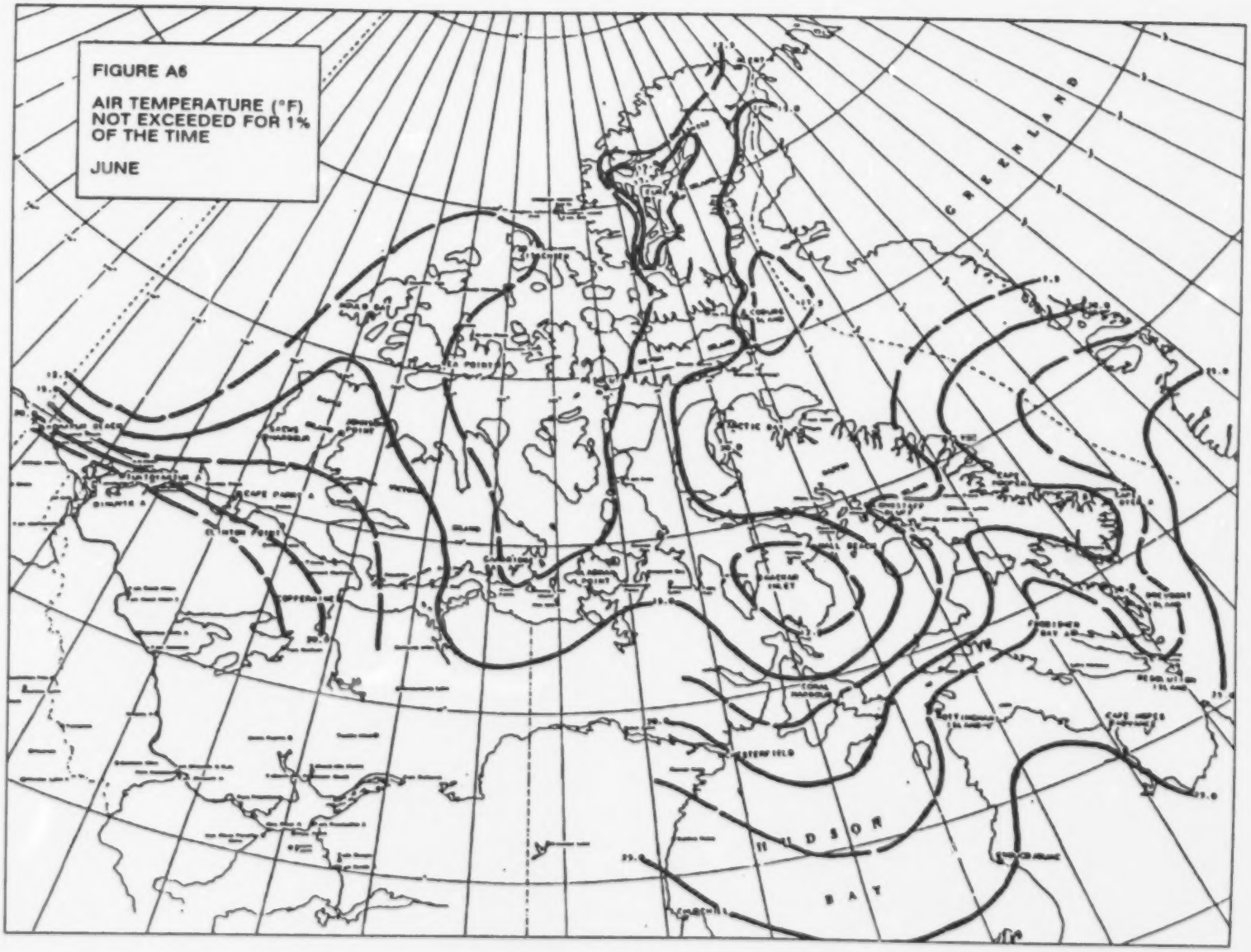


FIGURE A6
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
JUNE
GREENLAND
HUDSON BAY

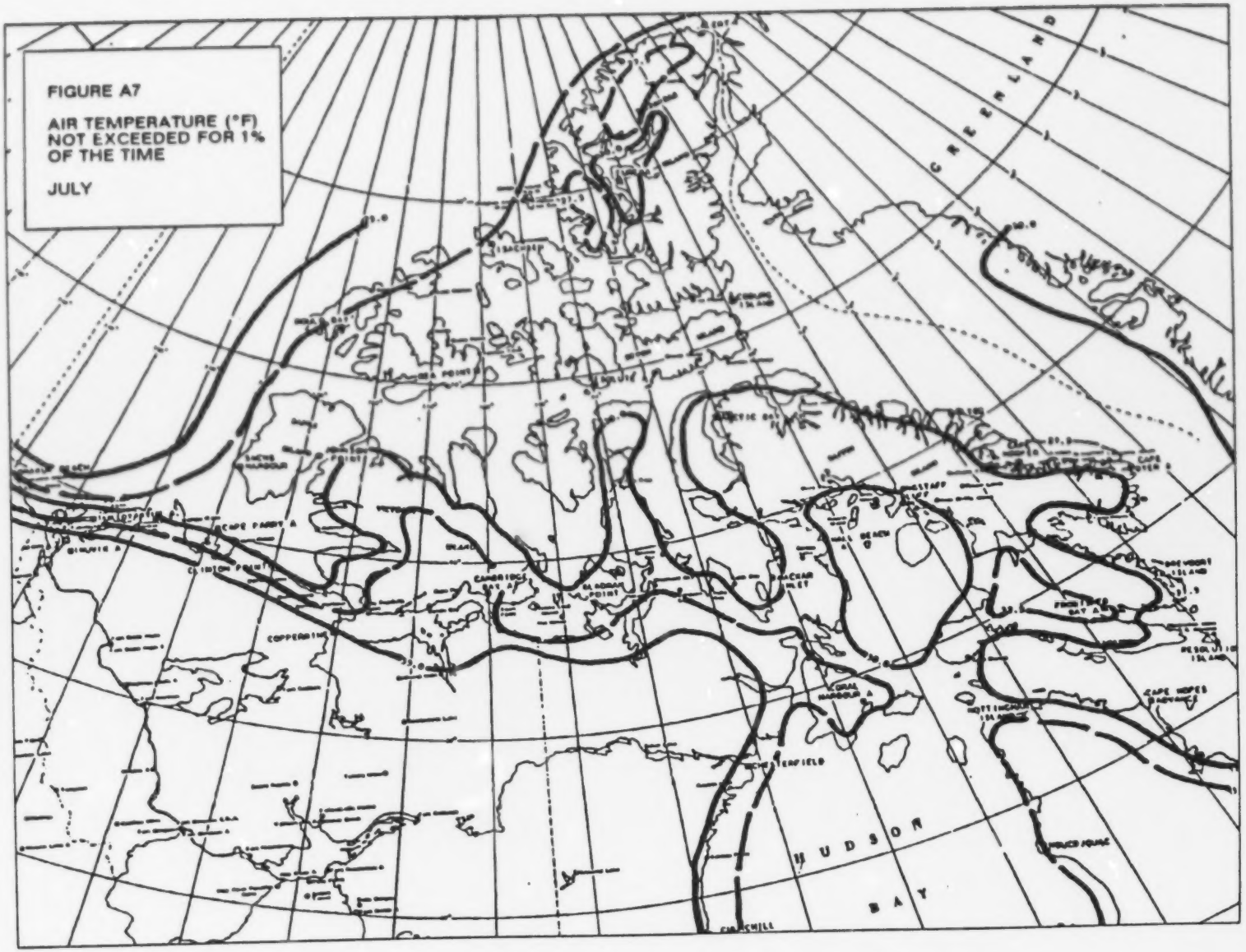


FIGURE A7
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
JULY
GREENLAND
HUDSON BAY

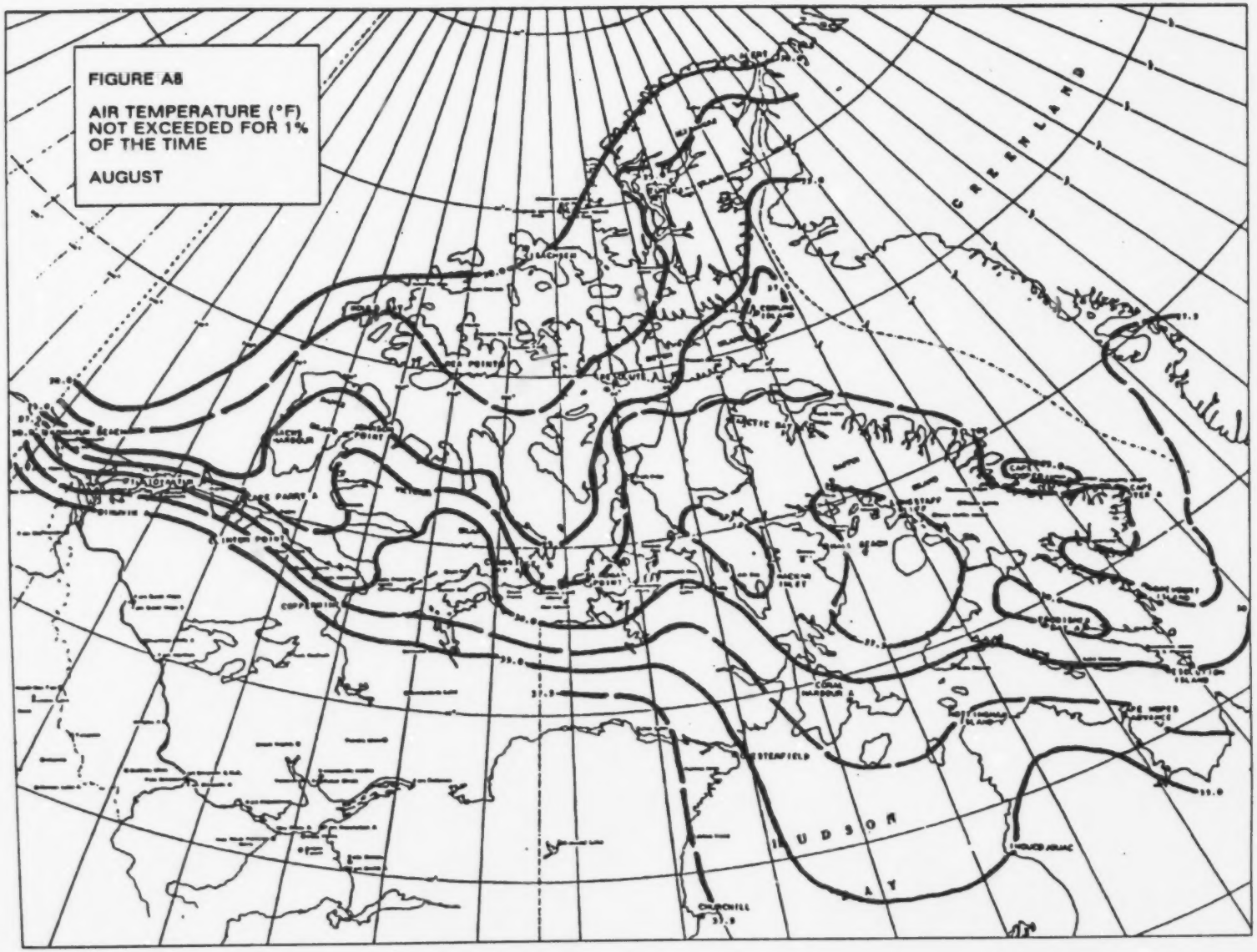


FIGURE A8
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
AUGUST

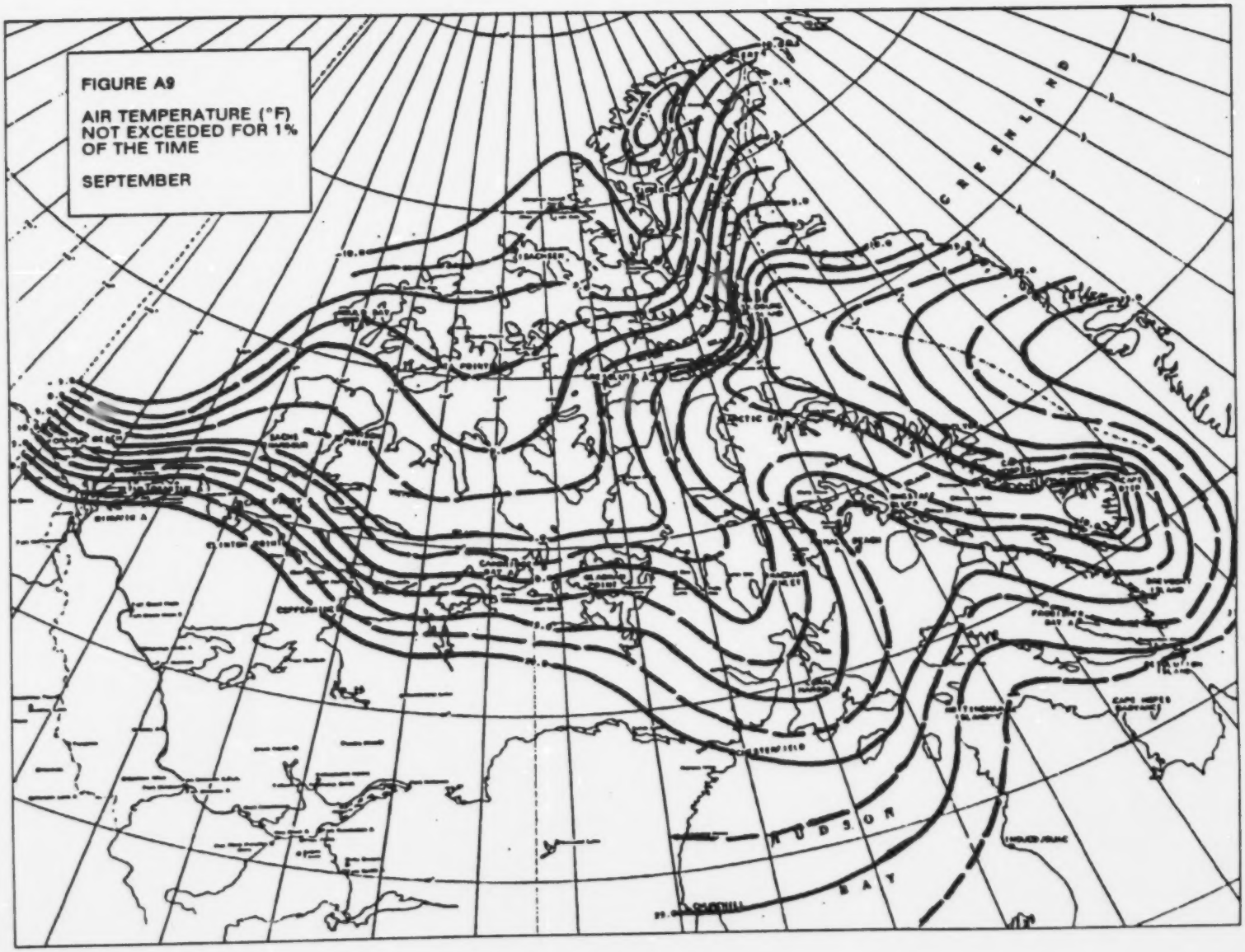


FIGURE A9
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
SEPTEMBER
GREENLAND
HUDSON
BAY

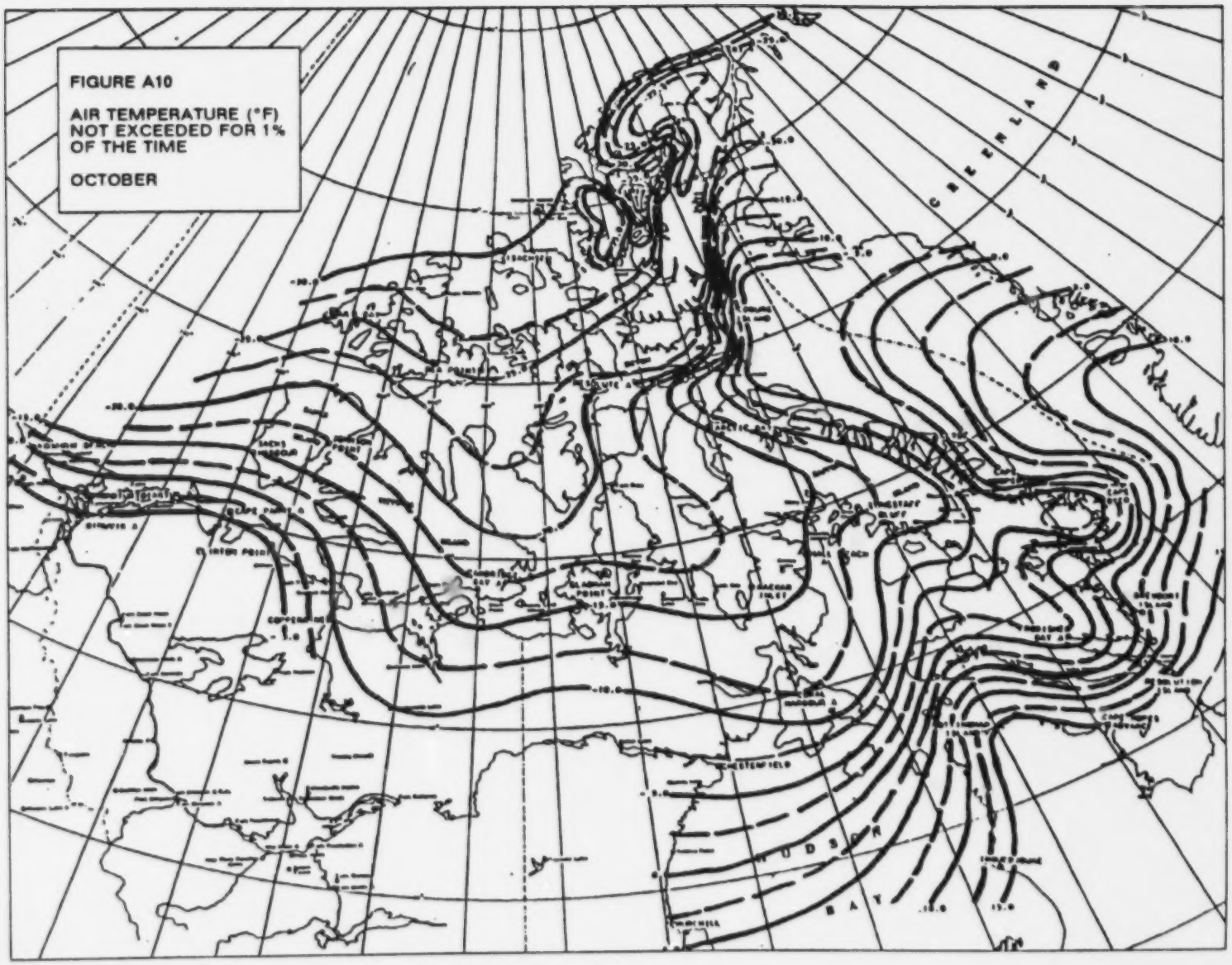


FIGURE A10
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
OCTOBER
GREENLAND
HUDSON BAY

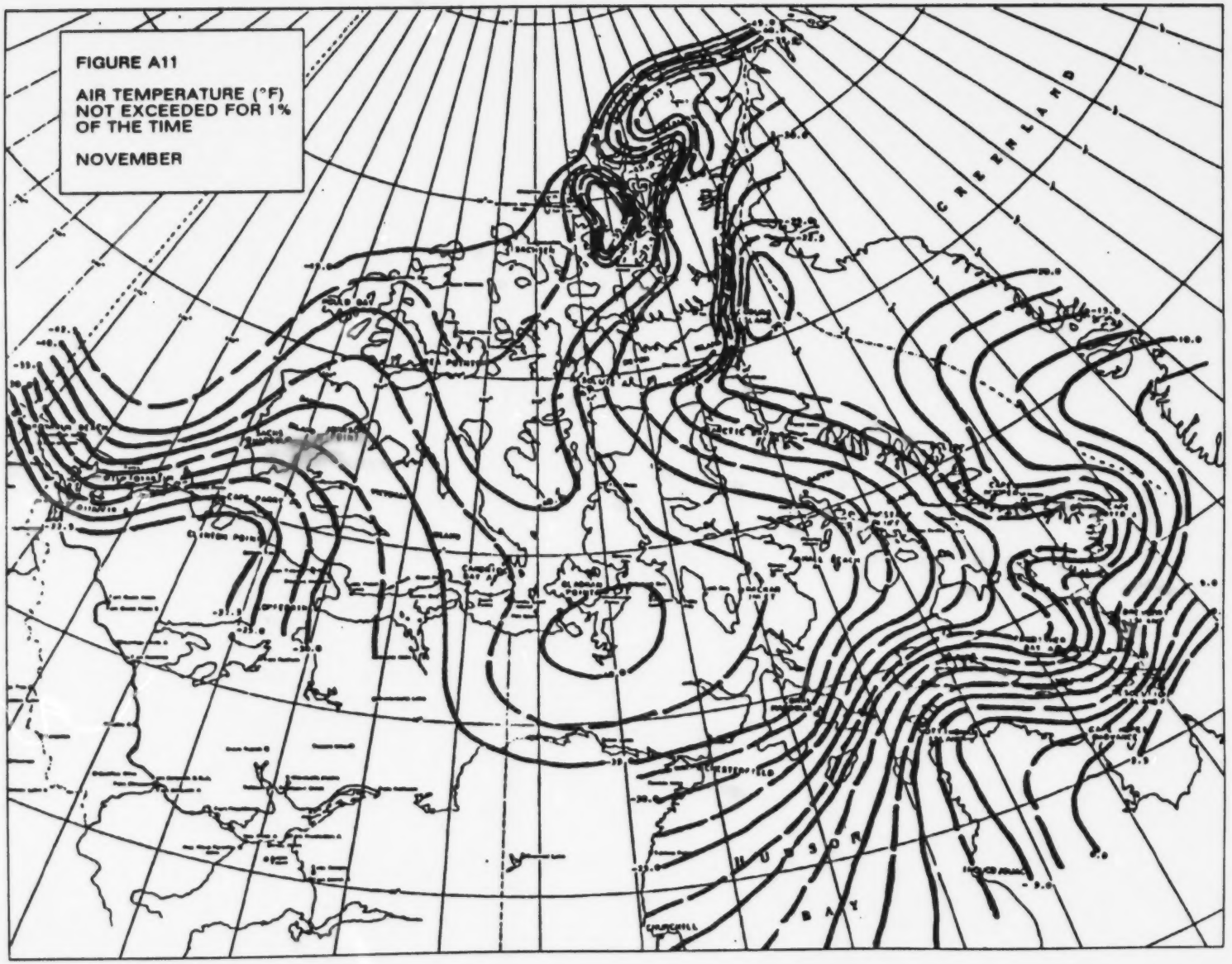


FIGURE A11
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
NOVEMBER
GREENLAND

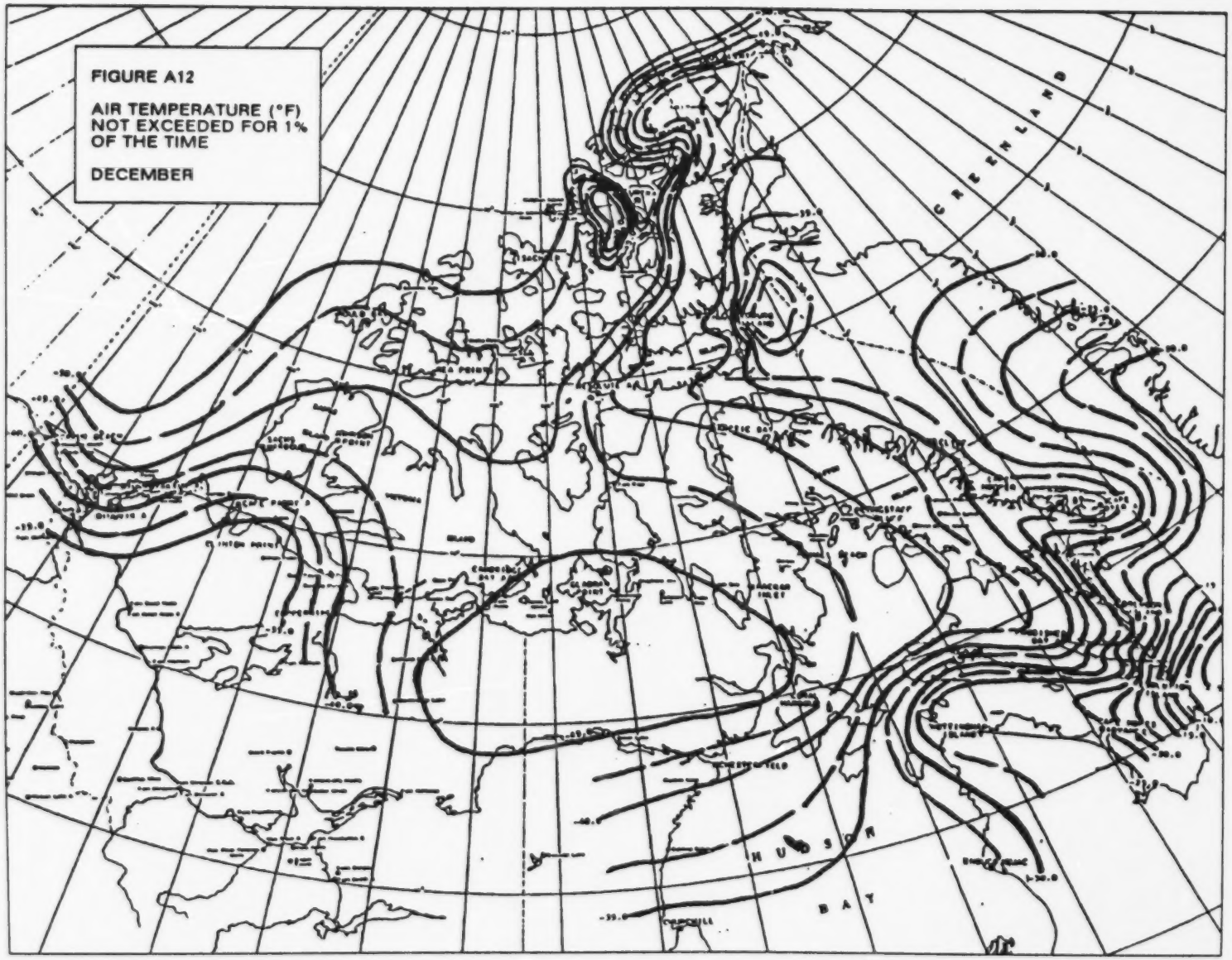


FIGURE A12
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 1% OF THE TIME
DECEMBER
GREENLAND
HUDSON
BAY

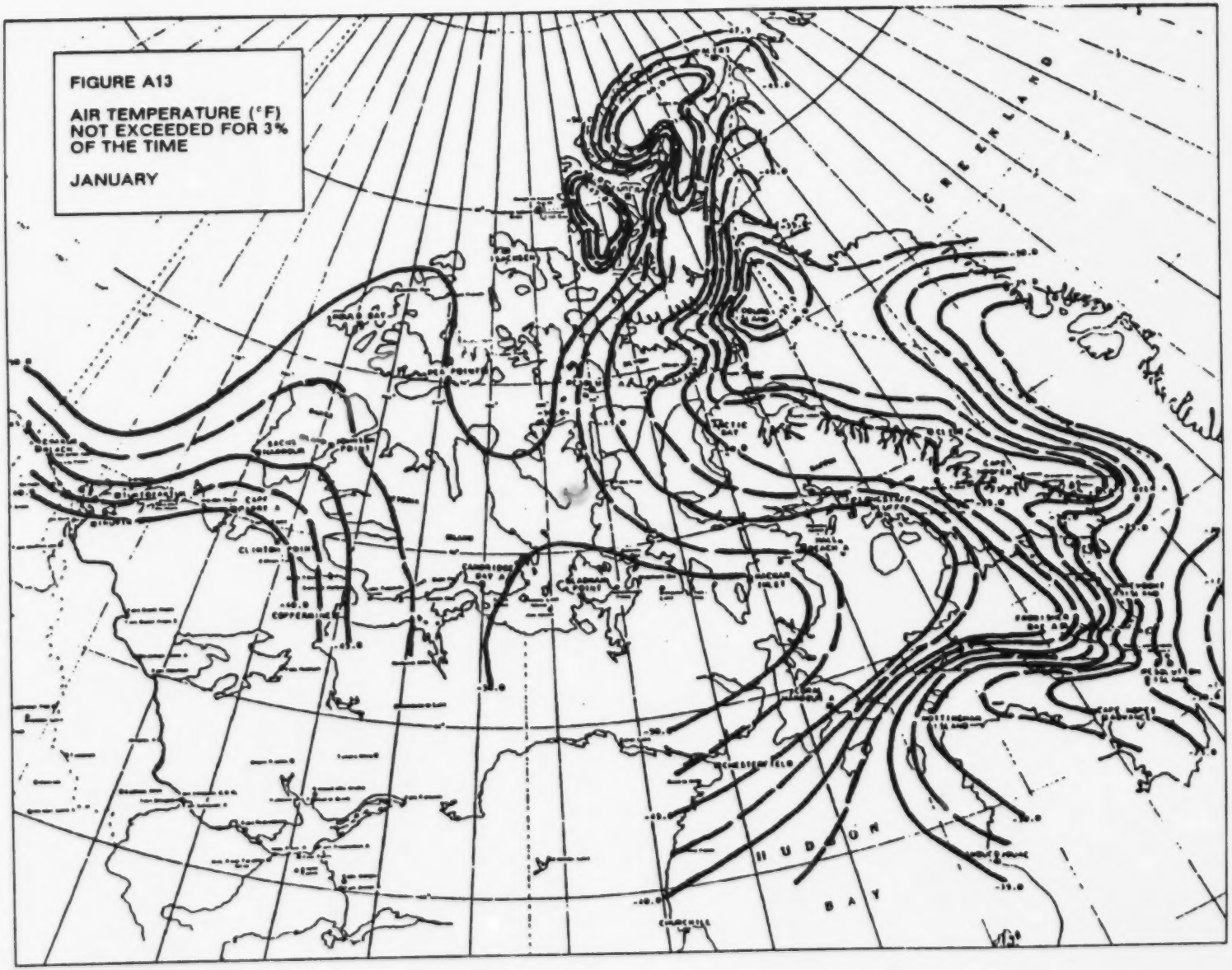


FIGURE A13
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
JANUARY
GREENLAND
HUDSON
BAY

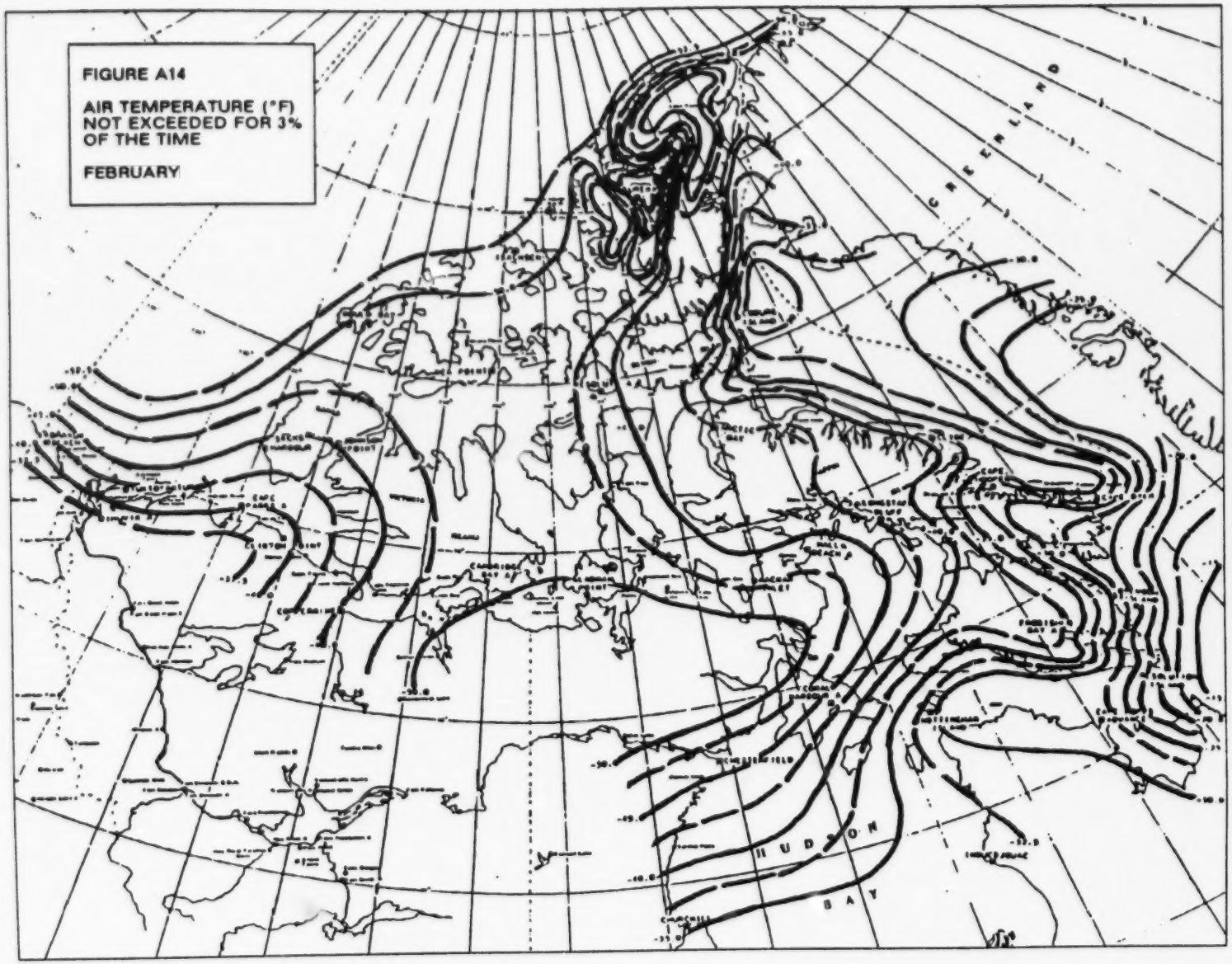


FIGURE A14
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
FEBRUARY
HUDSON
BAY

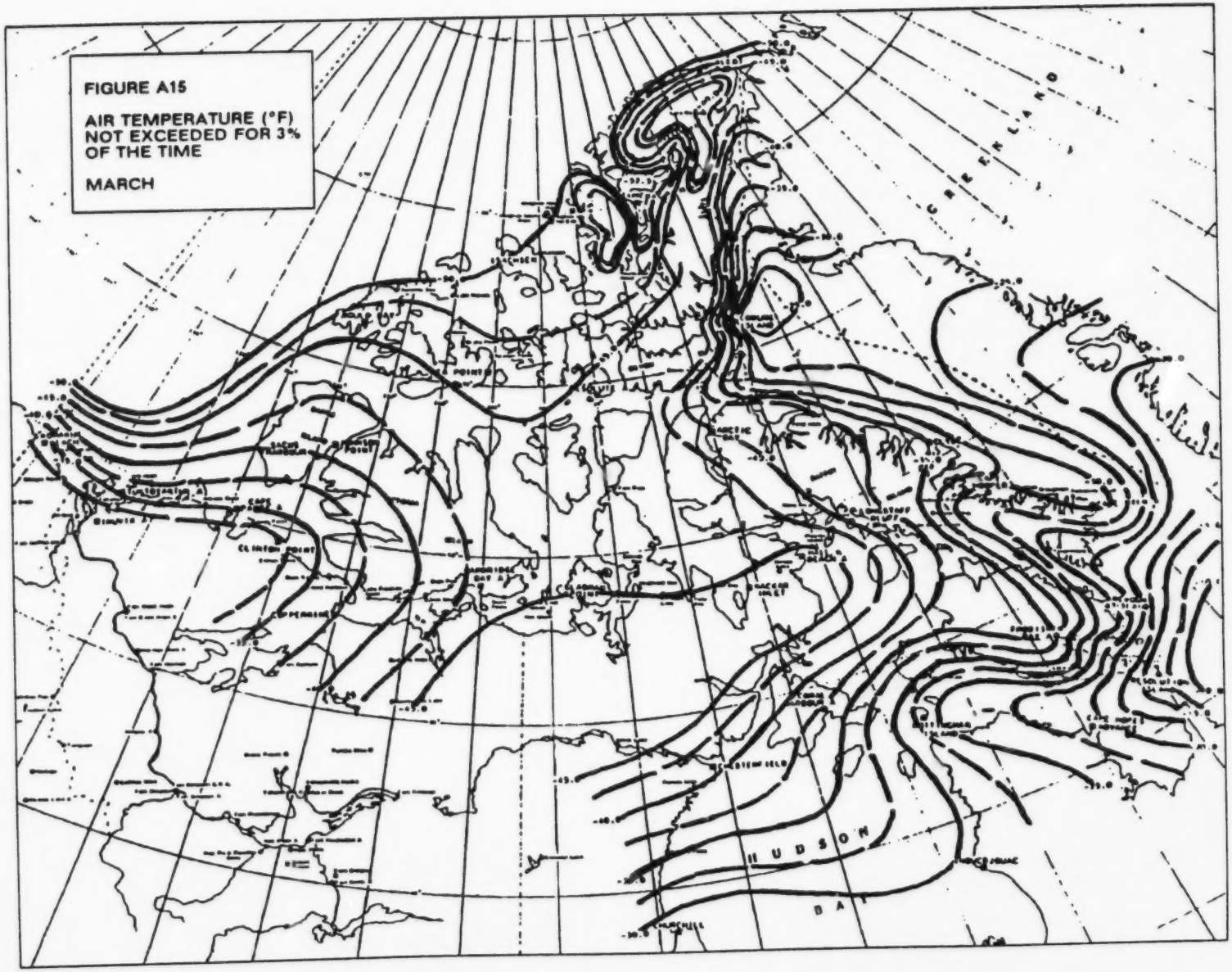


FIGURE A15
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
MARCH
HUDSON
BAY

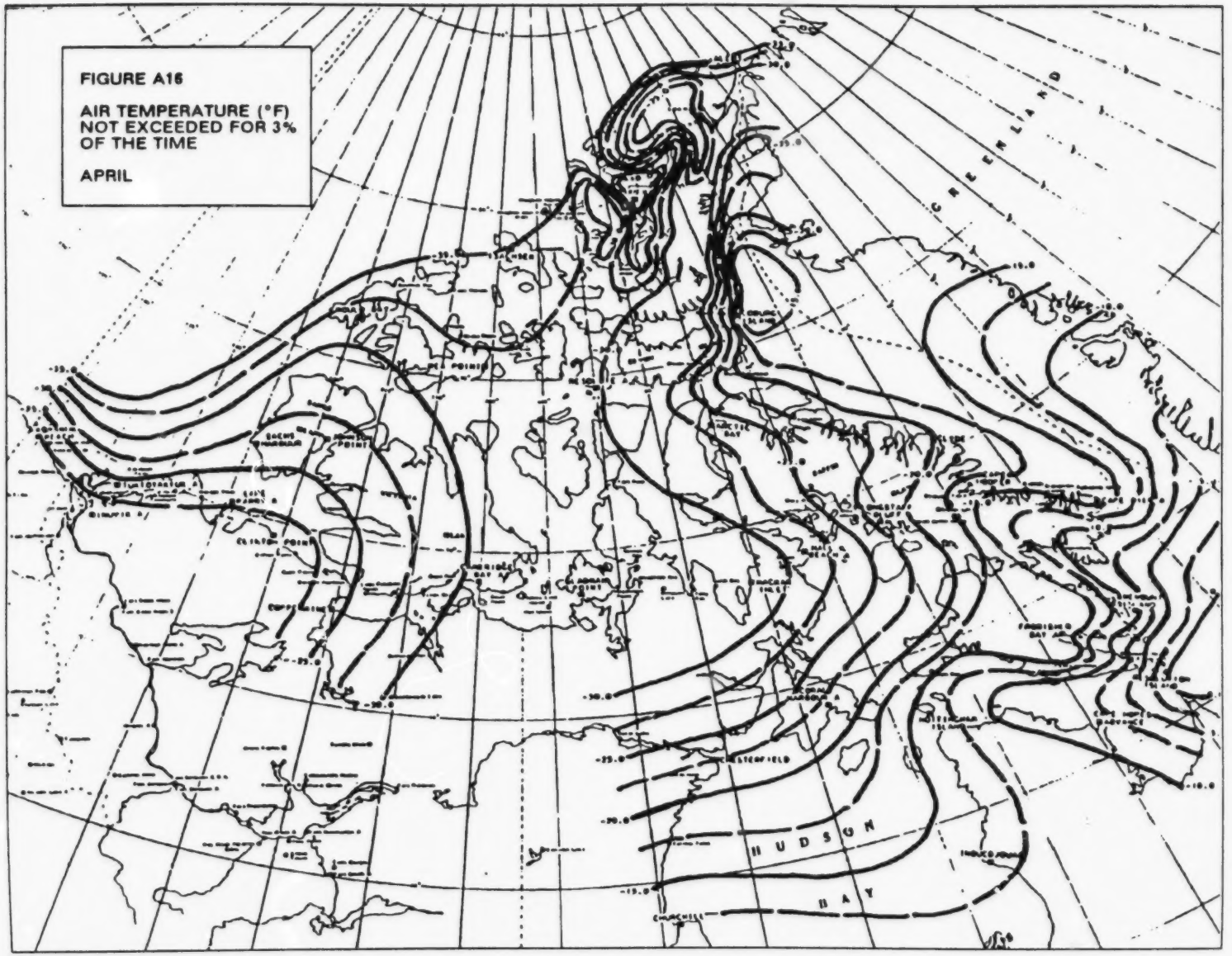


FIGURE A16
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
APRIL
GREENLAND
HUDSON
BAY

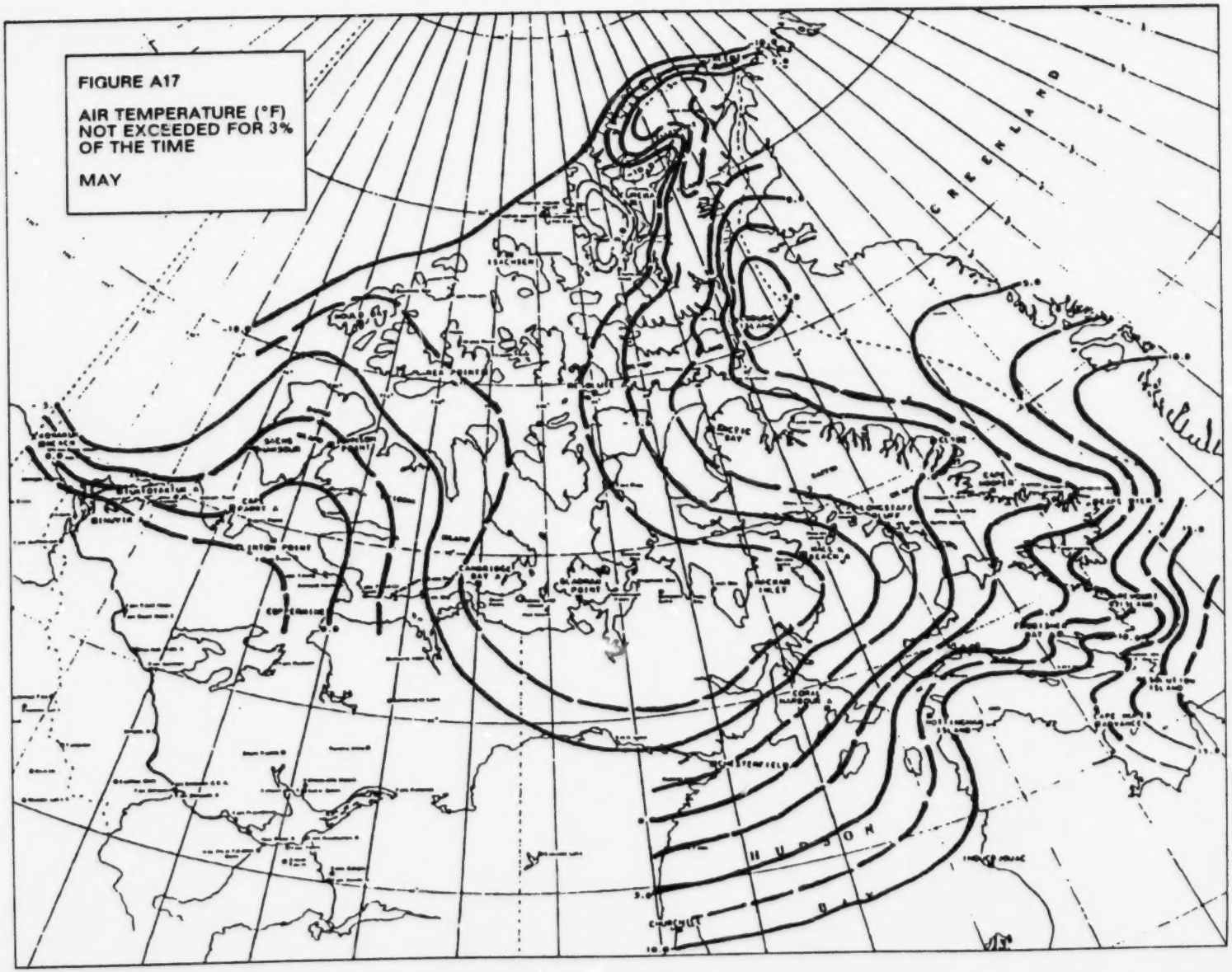


FIGURE A17
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
MAY
HUDSON BAY

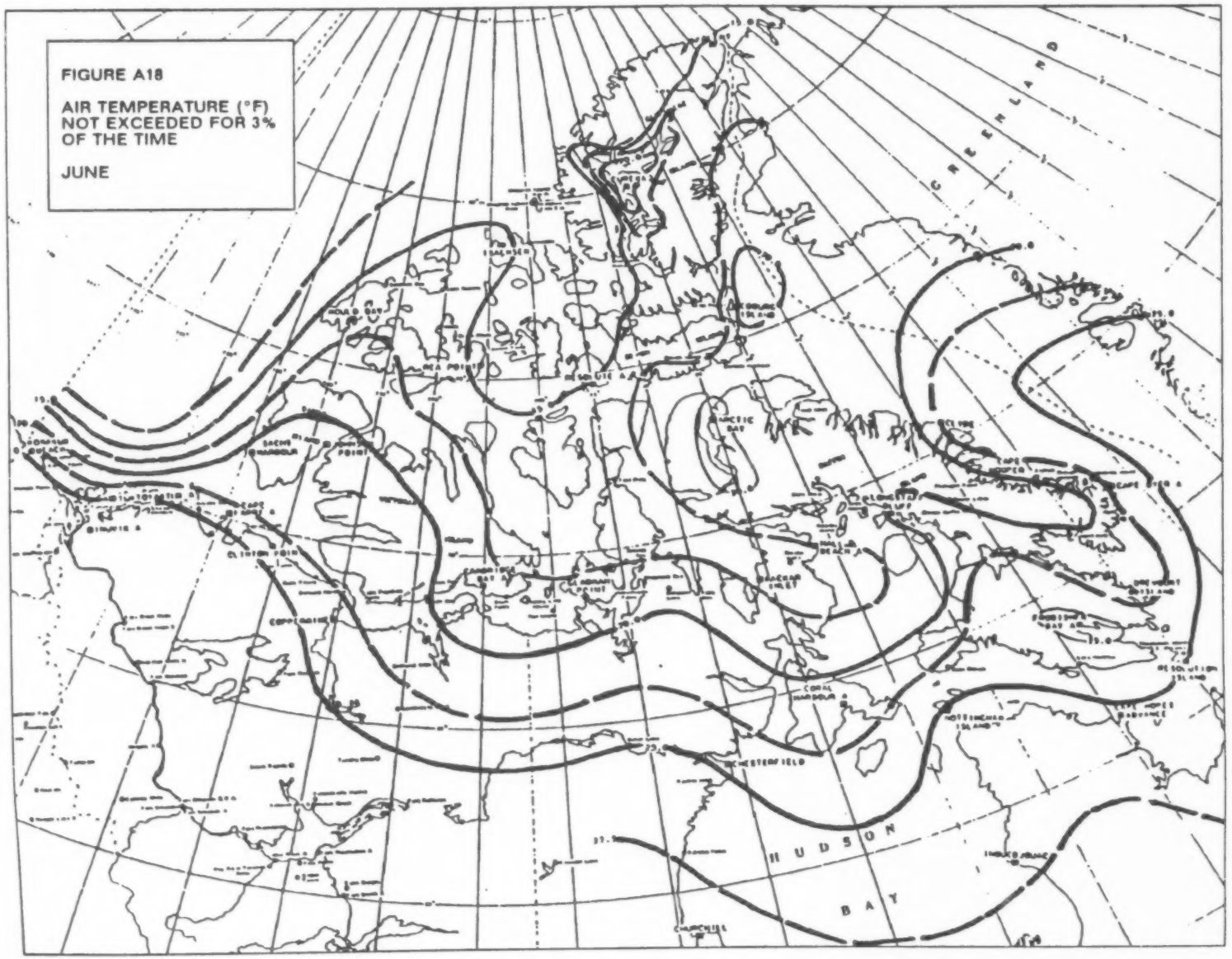


FIGURE A18
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
JUNE
HUDSON BAY

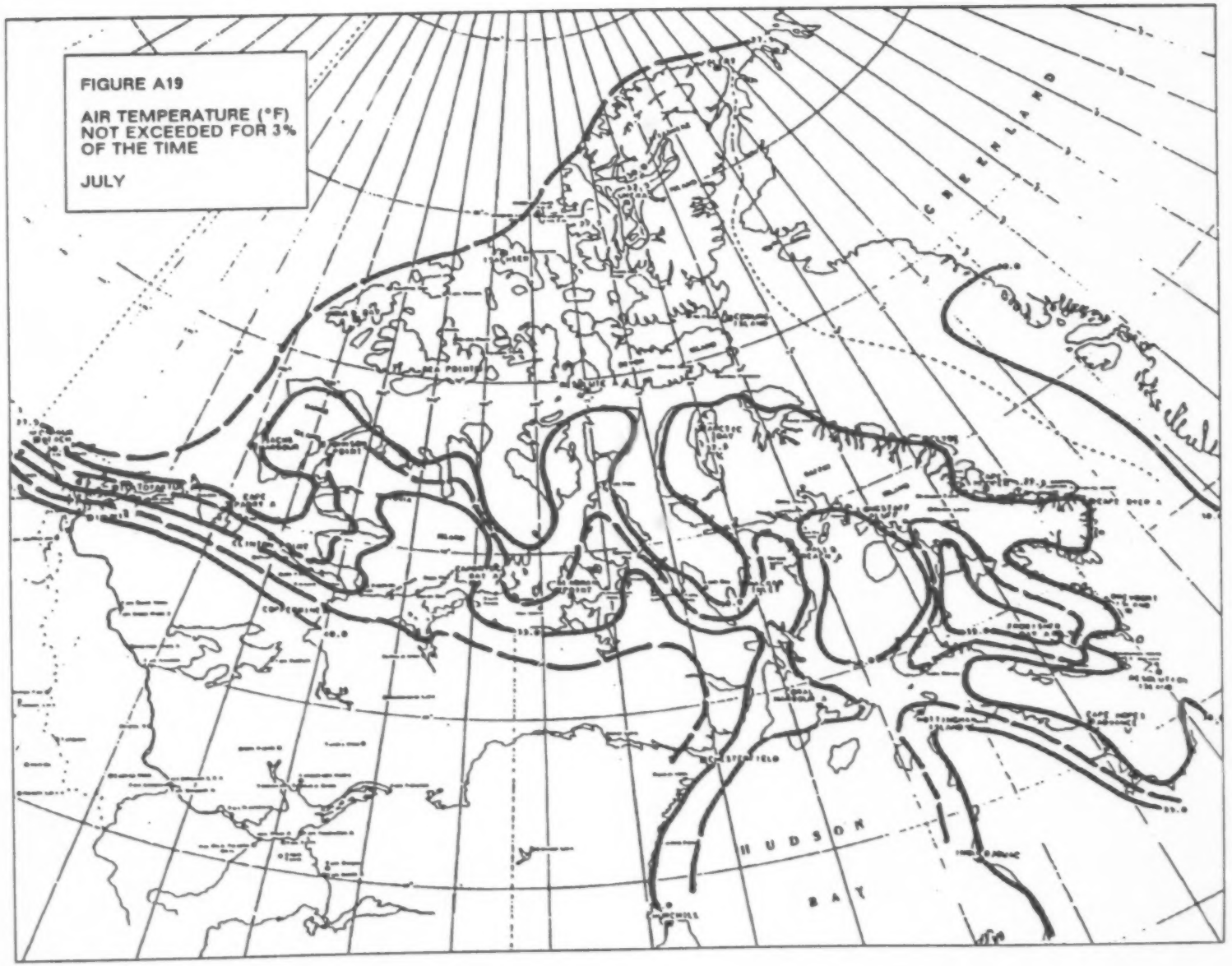


FIGURE A19
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
JULY
HUDSON
BAY

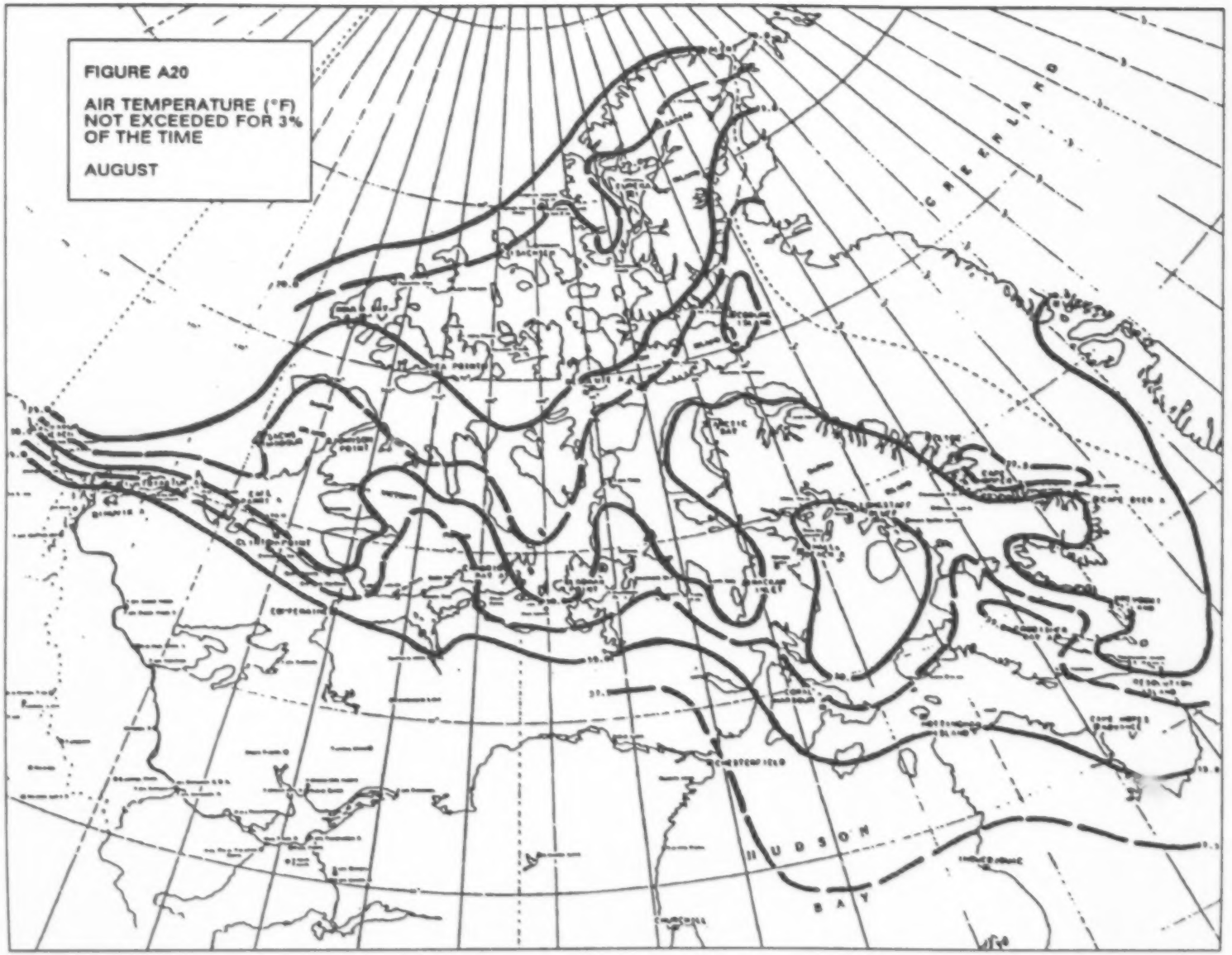


FIGURE A20
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
AUGUST
GREENLAND
HUDSON
BAY

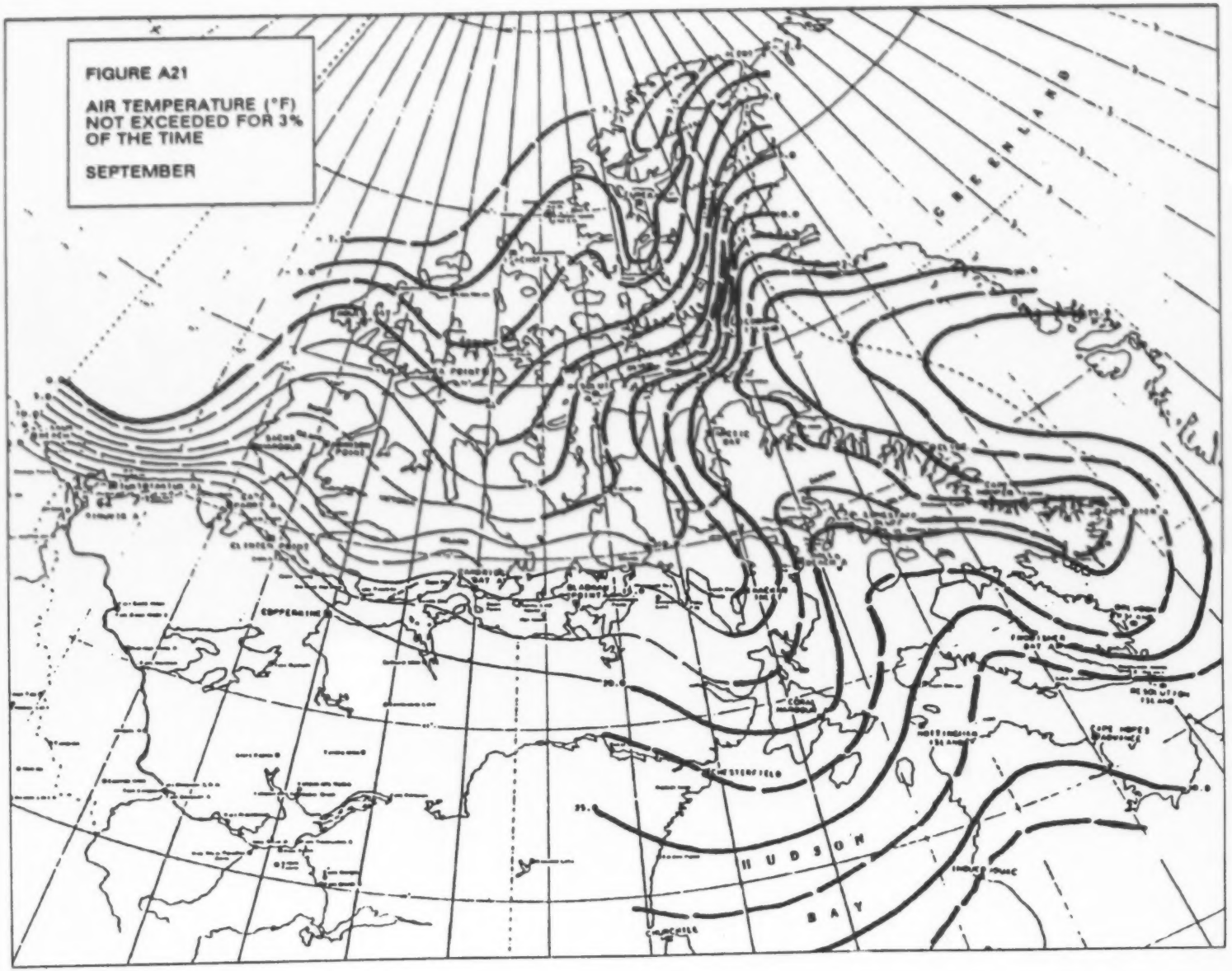


FIGURE A21
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
SEPTEMBER
HUDSON
BAY

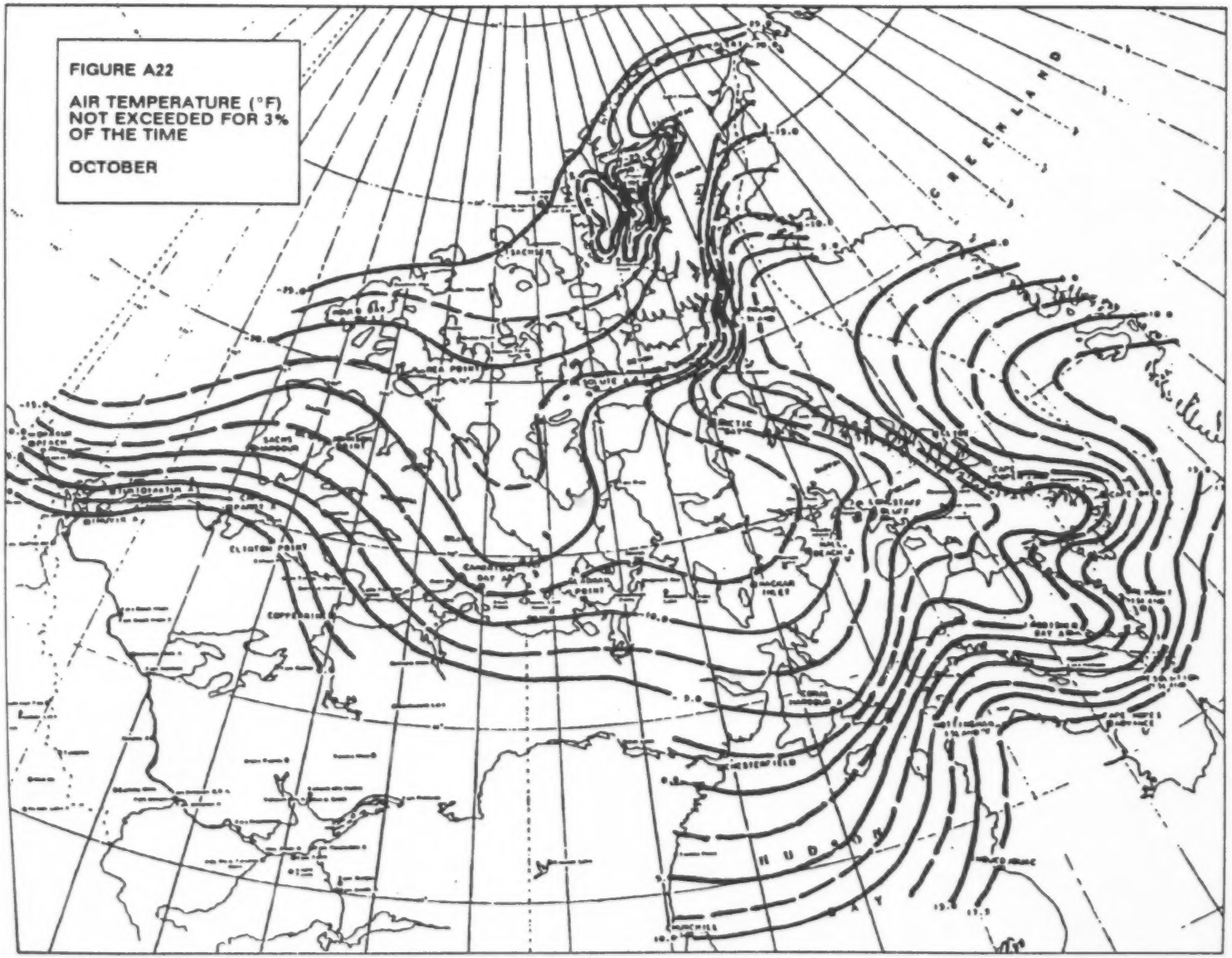


FIGURE A22
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
OCTOBER

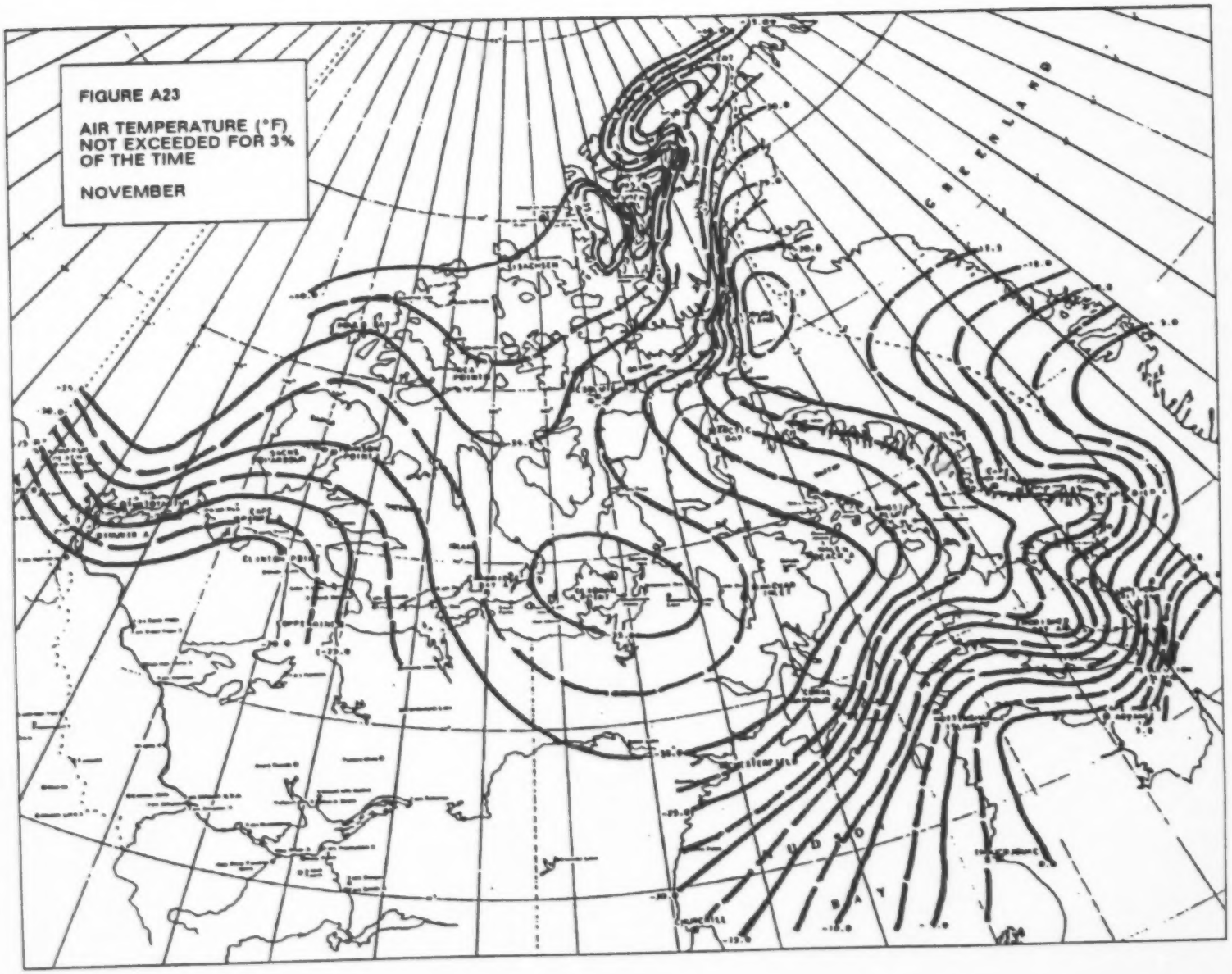


FIGURE A23
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
NOVEMBER

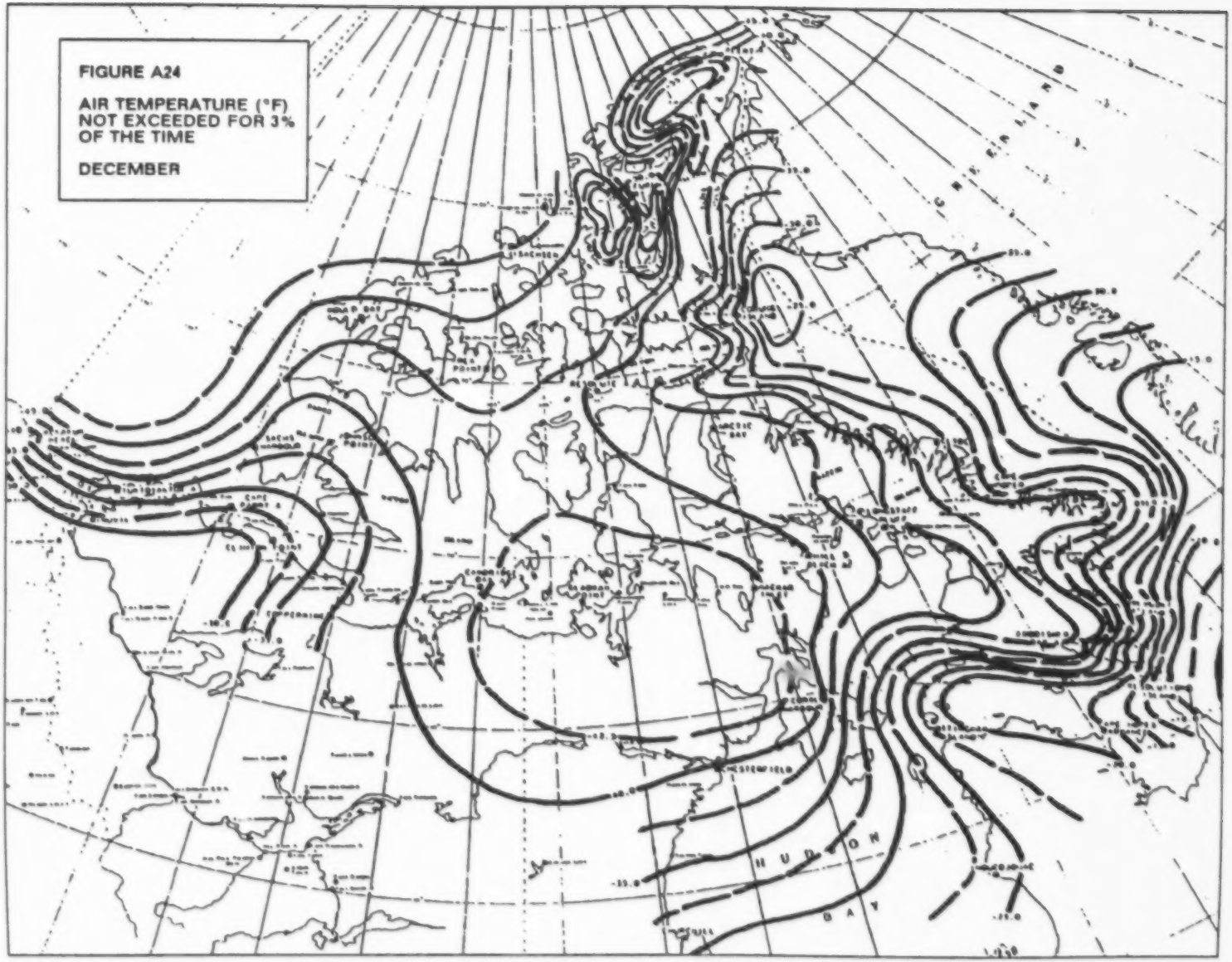


FIGURE A24
AIR TEMPERATURE (°F) NOT EXCEEDED FOR 3% OF THE TIME
DECEMBER
HUDSON
BAY